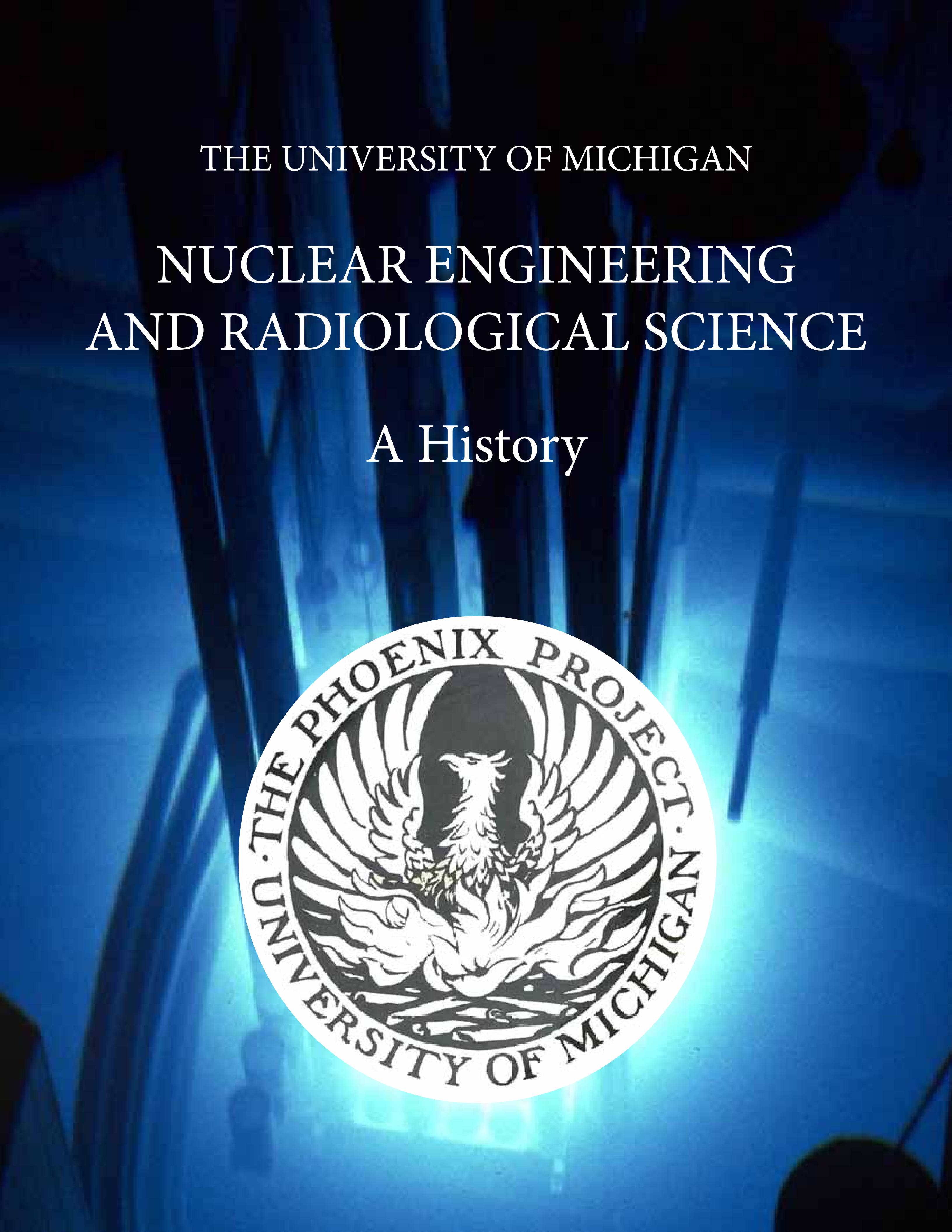
THE UNIVERSITY OF MICHIGAN

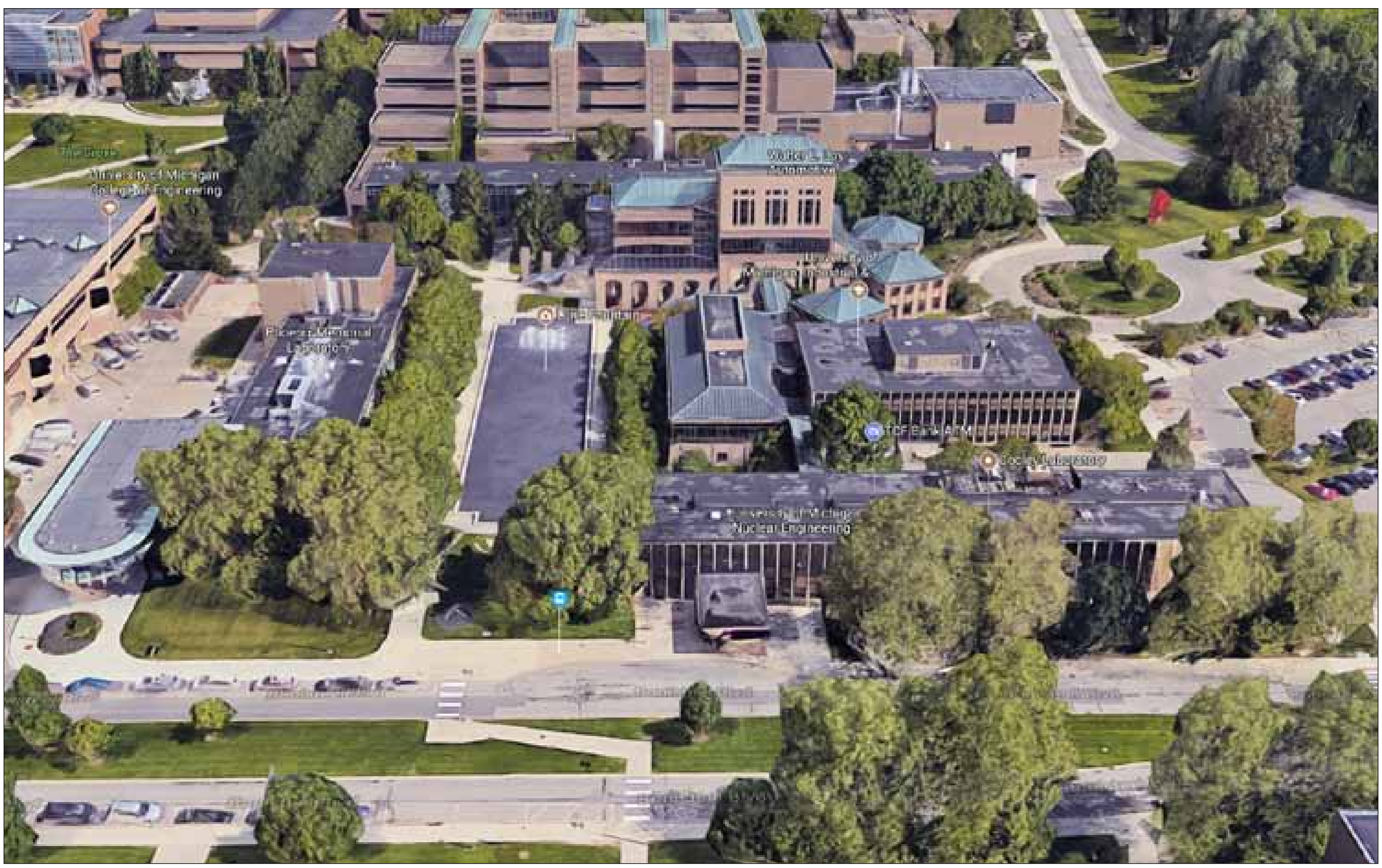
NUCLEAR ENGINEERING AND RADIOLOGICAL SCIENCE

A History



The University of Michigan Department of Nuclear Engineering and Radiological Sciences

A History



James Duderstadt (with the assistance of the NERS Faculty)

The Millennium Project
The University of Michigan
2001 Duderstadt Center
2281 Bonisteel Boulevard
Ann Arbor, MI 48109-2094

http://milproj.dc.umich.edu

Preface

This book is intended as a history of the Department of Nuclear Engineering and Radiological Sciences (NERS) — its faculty, students, staff, educational and research programs and its impact. The stories, images and data contained in the following pages document this remarkable history and influence over the past 70 years, during which time the Department has ranked among the top programs in nuclear science and engineering in the world.

Historical narratives have been provided by students and faculty members over the years. Much of the recent data concerning the Department was gathered by writer Kim Roth in her draft of a new entry for the University of Michigan's Encyclopedic Survey prepared for the University's Bicentennial in 2017. That work helped inspire this broader history.

Thanks are also due to Anne Duderstadt for assisting in the design and final editing of the book.

History for the current year (2018) has been drawn in large part from long-range planning documents prepared by the faculty for a recent accreditation review.

As the "scribe" for gathering these contributions for this history document, I would like to particularly acknowledge the admiration I have had for the Department over almost half a century of my association with it as a faculty member, colleague, and, today, "a next-door neighbor" on North Campus. It is my hope that this history accurately captures and conveys the remarkable impact its outstanding faculty, students, graduates and staff have had on the nation and the world during its long and distinguished history.

James J. Duderstadt
University of Michigan
2018

James Duderstadt lecturing on the history of the NERS Department

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Chapter 1

The Dawn of the Nuclear Age: The Michigan Memorial Phoenix Project

For over half a century, University of Michigan programs in nuclear science and engineering have provided national and global leadership, first through the research programs of the Michigan Memorial Phoenix Project and later through the educational and research activities of the faculty and students in the Department of Nuclear Engineering and Radiological Sciences (NERS).

The Michigan Memorial Phoenix Project

One of the most significant initiatives of the University of Michigan following World War II was the Michigan Memorial Phoenix Project, a major nuclear research program established by the University and funded by private gifts as a memorial to the 579 members of the University family who had given their lives to the nation during the war.

The University's enrollment grew rapidly after the war ended as returning veterans, particularly from the Pacific Theater, took advantage of the GI Bill. These students were determined that any University memorial to honor those who had made the supreme sacrifice for their country would not be "a mound of stone the purpose of which might soon be forgotten," according to a December 1950 *The Michigan Technic* history of the Phoenix Project. Instead, the students encouraged the University to create something that would aid in creating a war-free world for all mankind.

The University sent letters to many world leaders — Winston Churchill, Bertrand Russell, President Truman, and others — seeking advice. (It is interesting to read their responses, which are archived in the Bentley Library.) But, the WW II veterans in student leadership came up with their own concept and persuaded the Regents to do something quite unique and lasting.

Since the extraordinary destructive power of the atomic bomb had ended the war with Japan, where many of our veterans had served, the students recommended that the University create a permanent institute that would both conduct research and teaching on the peaceful uses of atomic energy. As a symbol, they selected the phoenix, the mythological bird that was consumed by fire every 500 years and arose revitalized from the ashes. The Michigan Memorial Phoenix Project thus would symbolize the growth of the benevolent atom from the flames of war.

In May 1948, the Regents adopted a resolution that "the University of Michigan create a War Memorial Center to explore the ways and means by which the potentialities of atomic energy may become a beneficent influence in the life of man, to be known as the Phoenix Project of the University of Michigan."

It is important to recognize just how bold this effort was. At the time, the program's goals sounded highly idealistic. Atomic energy was under government monopoly, and it appeared to be an extremely dangerous force with which to work on a college campus. The Phoenix Project was the first university attempt in the world to explore the peaceful uses of atomic energy, at a time when much of the technology was still highly classified. As reported in the December 1950 issue of *The Michigan Technic*, University President Alexander Ruthven called the Phoenix project "the most important undertaking in the University's history."

President Ruthven gave a particularly moving address on Memorial Day 1948:

It is traditional with the people of our nation to pay eternal tribute to their hero dead. Through countless communities the monuments of five major wars stand as reminders of their sacrifice and heroism. But it has been one of the frustrations of man that no monument of his making can ever match the courage and conviction of those who made the supreme sacrifice. Can there be a fitting memorial for the war dead? Can there be a fitting memorial for the heroes of the war that produced the atom bomb?

There is only one appropriate kind of war memorial — a memorial that will eliminate future war memorials.

We at the University of Michigan believe this is possible. Our students, alumni and faculty members have conceived, under the name Michigan Memorial Phoenix Project, a war monument that may well point the way to the elimination of wars.

The Phoenix Project proposes to turn a weapon of war into a potent instrumentality of peace. It proposes to do research with atomic tools solely in the interest of man's well-being. Through it a leading American university will send forth great scientists, engineers and other scholars, and will open vast physical resources in an effort to turn the atom into pathways of peace. Here doctors, chemists, biologists and others will seek cures for "incurable" diseases; engineers will convert new knowledge into methods of better living; social scientists will attempt to evaluate and chart the social, economic and cultural implications of the atomic age.

Here, like the Phoenix bird of ancient legend, the atom's force will rise from the ashes of its own destruction and point the way to a better, fuller, happier life than man has ever known.

The monument proposed by Michigan transcends the conventional "living" memorial. It will be a dynamic, working, life-serving memorial, it provides a rare opportunity to answer the challenge of our hero dead: "To you, from failing hands, we throw the torch; be yours to hold it high."

The University was paying tribute to the sacrifices of its men and women during the war by accepting the momentous responsibility of studying the peaceful applications of atomic energy.

Even President Eisenhower highlighted the importance of the Phoenix Project, as reported also in *The Michigan Technic* in December 1950: "Few causes are more urgent today and more noteworthy of your support. In war or in peace, the atomic research being done at the University of Michigan...will strengthen America..." Little wonder that the project received worldwide attention during those early years.

The Early Years of the Michigan Memorial Phoenix Project

In the early 1950s, the Michigan Memorial Phoenix Project launched a fundraising campaign under the leadership of University President Alexander Ruthven and Albert Lang, president of the General Electric Company. The fundraising committee also included three students who were all veterans of World War II. The Phoenix Campaign quickly grew into a well-organized national effort that raised $6.5 million for a research building, a research endowment and, thanks to a $1 million gift from the Ford Motor Company, a nuclear reactor, named the Ford Nuclear Reactor. Built on the University of Michigan North Campus, the reactor was the third research reactor in the United States. It went critical in 1957 and operated 24 hours a day for the next 50 years.

Eventually the Phoenix Project would obtain over $20 million (amounting to more than $200 million in today's dollars) from private, corporate and foundation sources. Over 30,000 alumni and 350 firms participated, and the effort represented the largest fundraising campaign in UM history until the $55 million campaign for the University's sesquicentennial in 1963.

In its early years, the Michigan Memorial Phoenix Project stood practically alone among such major research enterprises in that it did not seek funds from government agencies. All of its support came from private sources. This was by design, and for two reasons. First, the Project was a memorial to the University of Michigan students, faculty and alumni who died in WW II, and it seemed fitting for it to be supported by members of the University family. And second, it was important for the Phoenix Project to maintain freedom of investigation through independently-financed research. According to a July 1963 article in *The Michigan Alumnus*, "The managers of the Project point out that 'the young research man, the unusual

EXTRA **The Michigan Daily** EXTRA

Latest Deadline in the State

ATOM RESEARCH CENTER TO BE 'U' WAR MEMORIAL

Planning, Study Back of Project

Year and Half of Work Follows Original Student Legislature Idea

Memorial Is Greeted With Enthusiasm

Gains Support, Pledges of Aid

Harnessed for Humanity

ATOMIC ENERGY UNLEASHED—

DYNAMIC REACTION:

Students Assure Phoenix Backing

Phoenix Plan To Benefit Man

Huge Program Will Probe Peaceful Application of Atom

An all-out offensive to convert the nightmare of Nagasaki into a living and lasting force for the betterment of man was launched today by the University in memory of its students and faculty members who died in World War II.

President Alexander G. Ruthven announced the establishment of the "Phoenix Project"—the world's first research institute devoted exclusively to exploring the peaceful and humanitarian applications of atomic energy.

Project Will Aid Research Coordination

War Memorial Is Functional

IT *HAD* TO HAPPEN IN A COUNTRY LIKE THIS

On July 16, 1945, on a desert in New Mexico, a blinding flash ushered in the promise of a new era in our civilization. With electric enthusiasm, we caught sight of new horizons in medicine, sociology, and industry.

In the months that followed, there was an atmosphere of revolution which atomic fission was supposed to create. We heard of breath-taking cures, of a better life for all mankind, of incredible scientific progress. Throughout the nation and world the hopes of people were lifted higher and higher. Everyone was sure that something momentous was at hand.

* * * *

But people who take the trouble to investigate—even now, three years later—discover quickly that something apparently went wrong with the prophecies.

In many places hard work is being done in an effort to harness atomic fission for power and industry—work largely financed by the Government for its war potential, or by industry for its profit potential. *But progress is being made at a snail's pace where it matters most: in extracting the secrets of atomic fission for the physical betterment of mankind.* Here, in a large measure, the atom promise remains little more than a promise.

* * * *

In February, 1947, the Atomic Commissioner of France complained that Americans, with all their facilities, genius, and money, could quickly create an atomic bomb to destroy civilization, but are nowhere to be found when the only thing to gain is a better world.

In a country like this, such a challenge cannot long be ignored.

Our tradition, since the founding of the country, has been one of getting things done. European intellectuals in the past have reflected upon our intellectual maturity as a people; nations overseas that have taken our money and wanted more have accused us of having too much; *but no one has ever before accused the American people of shirking an important job for lack of energy, or organization, or determination to reach an objective.*

So it was destined that someone in this country would sooner or later shoulder the responsibility of providing the necessary inspiration, organization, funds, co-operation, and determination to fulfill the humanitarian promise of atomic development.

The University of Michigan, one of the nation's greatest and largest, and presently having the most extensive alumni organization and widely distributed membership of any university, has picked up the gauntlet. It has assumed an important responsibility of leadership in getting the job done and will also join with private and public agencies in making atomic energy the servant and not the master of man.

To this end, the Board of Regents has approved the recommendation of the War Memorial Committee that a memorial be developed which will make a noted contribution to the well-being of mankind. The result is a plan to be known as The Phoenix Project—a project which symbolizes the conversion of the ravages of war into new life and hope.

The Phoenix Project of the University of Michigan is planned as a continuing, *working* memorial of the men and women of the University who died in World War II. It befits the purpose: it will help accomplish at least one of the major jobs that winning the war gave us an opportunity to do. It is committed to become an important factor in peacetime atomic research for humanitarian purposes: out of the horrors of the atomic bomb the men and women of Michigan are determined to help create a force for good, perhaps one of historic proportions.

* * * *

The Phoenix Project will consist of a memorial structure that will symbolize the task that is being undertaken to honor the memory of those who left the University to fight and die for their nation. There will be laboratories in which important and continuing work will be done. There will be a skillfully organized information exchange which will be at the service of the hundreds of specialists in various fields of medicine and science who are now or who will be working independently toward the objectives which, someday, we can reach. There will be facilities and meeting places for those who wish to help direct world thinking toward the development of all the peacetime benefits and potential benefits of atomic fission. In time, it is hoped that the sociological, historical, legal, philosophical and ideological aspects of an atomic era will be discussed here. In short, it will be an action-and-thought-center for the development of atomic promises.

The Phoenix Project is a part of the University of Michigan, and it memorializes particularly a group of Michigan students; but it is a project for everyone who believes that Americans have a national responsibility to utilize history's greatest discovery for the *benefit* rather than for the *destruction* of mankind.

[The 20,000 students of the University of Michigan and the 125,000 alumni have assumed the responsibility of raising the funds necessary to make this project a practical, functioning reality. They are planning a united drive for funds, definite plans for which will be announced at an early date. Inquiries concerning the University War Memorial should be addressed to the Phoenix Project, University of Michigan, Ann Arbor.]

THE PHOENIX PROJECT OF THE UNIVERSITY OF MICHIGAN - ANN ARBOR idea, the initiative of the individual goes wanting in an atmosphere of group research, of central government laboratories."

At the time, atomic energy was under government monopoly, and much of the technology was highly classified. In fact, the actual plans for the nuclear reactor in the Phoenix Laboratory were classified during the early phases of its construction. Early courses in the science and technology of nuclear energy frequently also were classified and required a Q-Clearance from the U.S. Atomic Energy Commission.

But few could debate the point, however, that if the undertaking succeeded, the program would be an unusually fitting memorial to those who gave their lives for their country during WW II. As a living, productive effort, the Michigan Memorial Phoenix Project would find ways over the years to employ the atom to aid mankind, rather than to destroy it.

Although all programs in the University were involved in the Michigan Memorial Phoenix Project, the College of Engineering had a particular responsibility to develop both instructional and research programs in nuclear energy. A professor of electrical engineering, Henry Gomberg, was named the first director of the Phoenix Project. The Department of Nuclear Engineering that would utilize the facility was the first such degree program in the United States. The Phoenix Project enriched University life through visits by many distinguished scientists, such as Robert Oppenheimer and Hans Bethe. Its summer conference on nuclear science and engineering produced some of the most important early papers in the field. The Phoenix Project also provided support and facilities for the hundreds of nuclear engineers and scientists who have studied and trained in the Phoenix Memorial Laboratory.

Early Achievements of the Phoenix Project

The tremendous impact of the Michigan Memorial Phoenix Project has roots stretching back to several of the of the early University-wide research projects it supported:

• In 1950, Professor Donald Glaser's work to develop the bubble chamber for nuclear particle detection was first supported by a $1,500 Phoenix Project grant when he could get no other support. This effort would later earn him the Nobel Prize.

• In 1949, Dr. William Beierwaltes received a $2,000 grant to develop techniques to use radioiodine (I-131) in medical diagnostics, a grant that helped launch the field of nuclear medicine.

• In 1949, Professor Lloyd Brownell conducted experiments on the use of radiation to preserve foods and its effects on plant life. (For readers familiar with North Campus, this explains the greenhouse that long stood adjacent to the Phoenix Memorial Laboratory, where the addition to the Michigan Energy Institute now stands.)

Additional research by faculty across the University has been spurred by access to the Phoenix Memorial Laboratory and the reactor on campus and has contributed greatly to a broad range of fields, including nuclear power, nuclear medicine, radiological sciences, and fundamental nuclear physics.

• Therapy units were established to use Cobalt-60, x-rays and radio-isotopes for the diagnosis and treatment of cancer.

• A Radio-Carbon Dating Laboratory was established for the determination of the age of archaeological and geological material.

• Improved techniques for using radioisotopes to locate brain tumors were developed.

• A vaccine from irradiated larvae was tested for use in eradicating, at the time, the world's number one health problem, a parasitic disease known as schistosomiasis.

• Radiation effects on materials were studied and led to heat-resistant metals and to new plastics with greater strength.

• Legal codes were devised to regulate the use of nuclear energy and radiation by industry and to provide compensation for radiation injuries in those situations not adequately covered by existing laws.

The Phoenix Memorial Laboratory and the NERS Department have continued to make significant contributions to nuclear research and application, including

• The first observation of gravitationally induced quantum interference by Sam Werner, described in detail in a later chapter.

• Seminal experiments involving neutron scattering and spectroscopy in the 1960s and thereafter.

• The first demonstration of low-enrichment (non-weapons-grade) uranium fuel for research reactors, a major contribution to anti-proliferation in the 1980s, also described in more detail later.

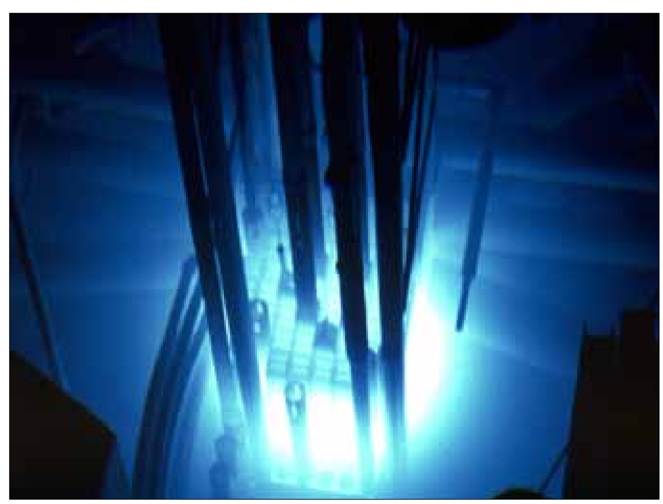
For its groundbreaking work in many areas, the Michigan Memorial Phoenix Project was recognized in 2001 by the American Nuclear Society as "a unique and pioneering atomic research program, as a permanent memorial to the University's soldiers who fought and died in World War II, and as a symbol of the University of Michigan's commitment to the peaceful and socially responsible use of science and technology."

Early Years of the Michigan Memorial Phoenix Project

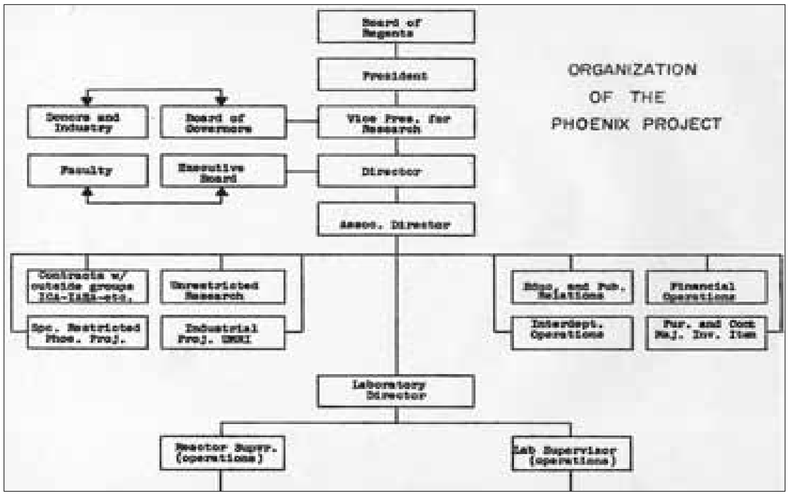
President Ruthven and the Memorial Campaign

Henry Gomberg announcing the Phoenix Project

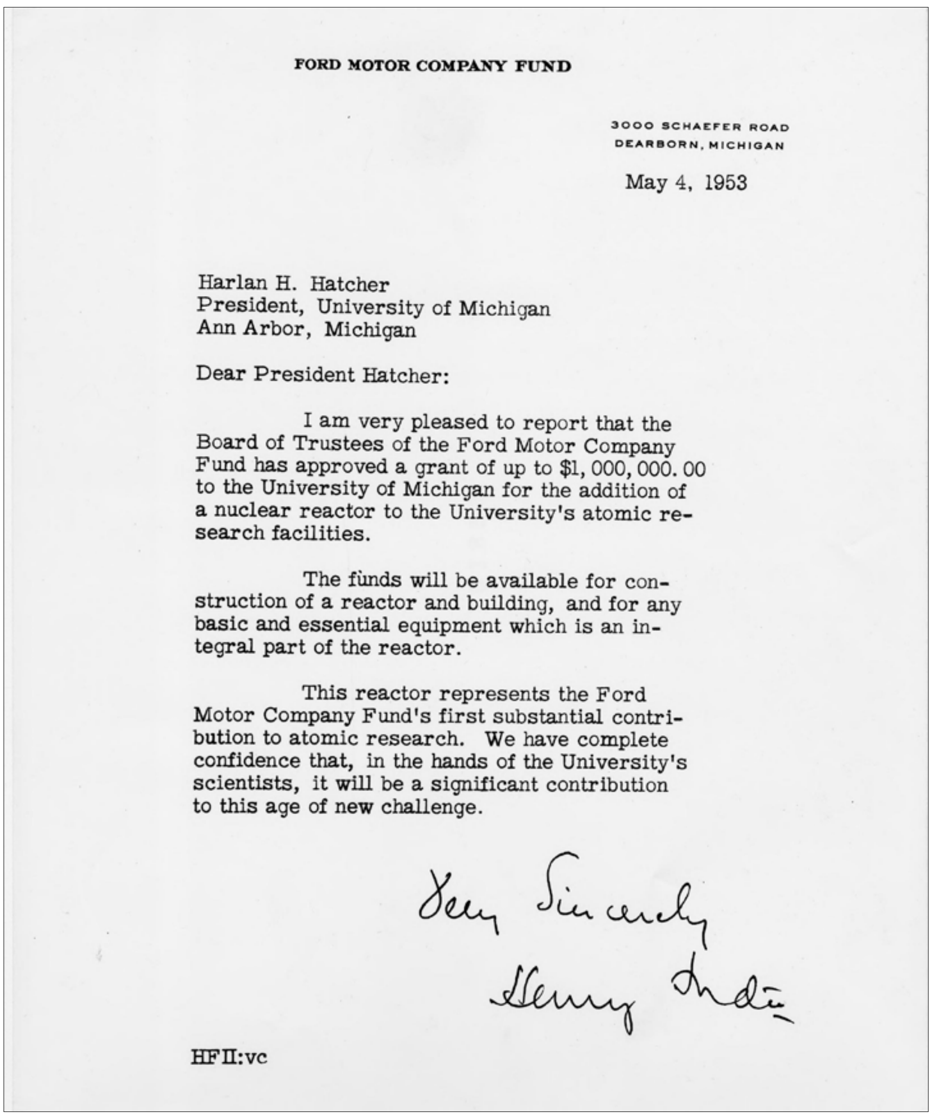
Michigan Memorial Phoenix Project Logo



The radiation glow from the Ford Nuclear Reactor



The Organization of the Phoenix Project



FORD MOTOR COMPANY FUND

3000 SCHAEFER ROAD
DEARBORN, MICHIGAN

May 4, 1953

Harlan H. Hatcher
President, University of Michigan
Ann Arbor, Michigan

Dear President Hatcher:

I am very pleased to report that the Board of Trustees of the Ford Motor Company Fund has approved a grant of up to $1, 000, 000. 00 to the University of Michigan for the addition of a nuclear reactor to the University's atomic research facilities.

The funds will be available for construction of a reactor and building, and for any basic and essential equipment which is an integral part of the reactor.

This reactor represents the Ford Motor Company Fund's first substantial contribution to atomic research. We have complete confidence that, in the hands of the University's scientists, it will be a significant contribution to this age of new challenge.

Very Sincerely
Henry Ford

HFII:vc

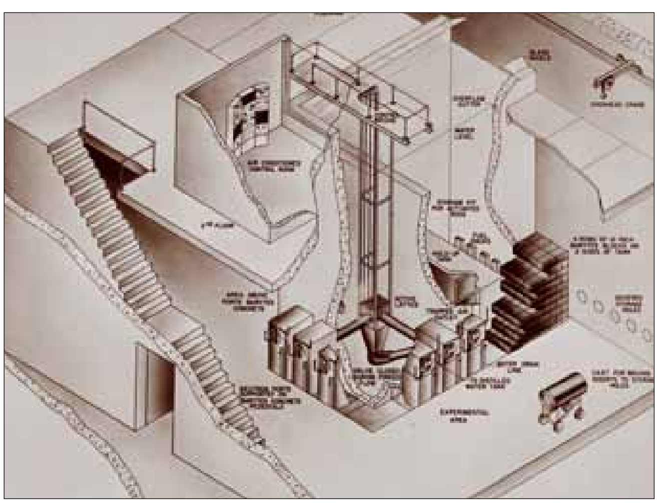
Letter from Henry Ford to fund the nuclear reactor


A drawing of the Phoenix Memorial Laboratory


Lloyd Brownell's PML greenhouse


The Ford Nuclear Reactor (FNR)


The FNR Nuclear Reactor core


A cutaway diagram of the FNR


PML particle veam detector

The Ford Nuclear Reactor in the Michigan Memorial Phoenix Project


A student tour of the FNR


PML Cobalt-60 Caves


The FNR bridge and control room


Jack Carpenter as a PML graduate student


Don Glaser working in the PML


Graduate students operating the FNR

Activities in the Phoenix Memorial Laboratory (PML)

Chapter 2

The 1950s: The Creation of the Department of Nuclear Engineering

Students, naturally, have been the primary beneficiaries of the research and teaching conducted through the Michigan Memorial Phoenix Project, both at the graduate and undergraduate level and across a number of disciplines, including nuclear engineering, physics, chemistry, mathematics and environmental health. Although all programs in the University were involved in the Phoenix Project, the College of Engineering assumed the responsibility to develop both instructional and research programs in nuclear energy.

Early Courses in Nuclear Energy

During the late 1940s and early 1950s, the University began to teach its first courses in nuclear energy in the Department of Aeronautical Engineering, initially in a graduate program for U.S. Air Force officers and later expanding in the 1950s into a graduate program in nuclear engineering, offering Master of Science and Doctoral programs in Nuclear Science and Nuclear Engineering.

By the early 1950s, the nuclear energy applications course material had been declassified and the course was offered to students throughout the UM Engineering College. This coincided with a growing interest in nuclear energy campuswide and nationwide. Professor of Chemistry Donald Katz established the Nuclear Engineering Division of the American Institute of Chemical Engineers and, in 1954 on the UM campus, he organized the first conference related to peaceful uses of atomic energy.

Faculty soon developed additional courses related to nuclear energy, including Radiation Measurements (Electrical Engineering, taught by William Kerr), Interaction of Radiation with Matter (also taught in Electrical Engineering, by Henry Gomberg) and Industrial Applications of Radiation (Chemical Engineering, taught by Lloyd Brownell).

In 1952, an interdepartmental committee appointed by the dean of engineering formally established a graduate program in nuclear engineering that would offer master's, doctoral and professional degrees. At the same time, the University was proceeding with plans to construct a research reactor as part of the Phoenix Project.

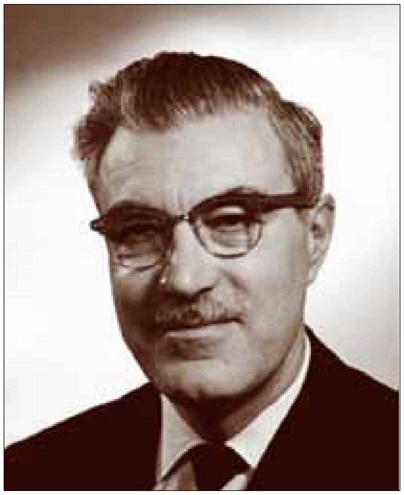
The Nuclear Engineering graduate program and Ford Nuclear Reactor, both dedicated to research into peaceful uses of nuclear energy and nonproliferation, drew widespread attention and many new students to the UM campus for graduate work. The first master's degree was awarded in 1954.

The following year, the UM chapter of the American Nuclear Society (ANS) was officially chartered. It was the first ANS student chapter in the country.

By 1958, three Nuclear Engineering doctoral degrees had been awarded, to Medea Iriarte, Terry Kammash and Fred Hammitt. Kammash and Hammitt subsequently joined the NERS faculty, and Kammash would serve as graduate chair. Enrollment stood at about 110 graduate students in 1958, and the program employed eight faculty, some on a part-time basis: Gomberg, William Kerr, John King, Paul Zweifel, Edward Martin, Richard Osborn, Lloyd Brownell and George West.

The Department of Nuclear Engineering

Strong interest and growth led to the official formation of the Department of Nuclear Engineering on July 1, 1958 by the Engineering College and University administration. Henry Gomberg (BS '41, MSE '43, PhD '51) was appointed its first chair. In 1960, he was also appointed director of the Michigan Memorial Phoenix



Donald Katz
Organized first UM NE efforts

Henry Gomberg
NE Chair 1958-1961

William Kerr
NE Chair 1961-1974

Project and served in these dual roles until 1961.

Gomberg's leadership, and the leadership of the chairs who succeeded him, played an important role in the Department's growth, continuity and success.

The Department utilized the facilities of the Phoenix Project's Phoenix Memorial Laboratory and the Ford Nuclear Reactor, the third university reactor in the country. The reactor reached criticality in 1957.

In 1965, undergraduate courses in both nuclear engineering and science engineering (later engineering physics) were introduced. The Department's early focus was on nuclear reactors, nuclear fusion and nuclear materials but later broadened to include nuclear measurements, radiological health and medical physics. In 1995, the name was changed to the Department of Nuclear Engineering and Radiological Sciences (NERS).

Michigan's nuclear engineering program and the associated Michigan Memorial Phoenix Project were the first such university programs in the world. Throughout its history, the NERS department has ranked #1 or #2 in the world (with Massachusetts Institute of Technology). Its faculty have produced several classic textbooks in the field. During its 50-year history it has granted 694 Bachelor of Science degrees, 488 Master of Science degrees and 490 doctoral degrees. On a per-faculty basis, the Department has long led both the College of Engineering and the University in the number of doctoral degrees granted. Its graduates have gone on to leadership positions in all aspects of nuclear energy: industry, government and higher education.

Of course, times and challenges change. Although the Ford Nuclear Reactor, with its two-megawatt (MW) power level and 24-hour operation, was widely regarded as the nation's leading university research reactor, in 2002 the University president made the decision to shut down and decommission the reactor, a decision strongly opposed not only by the Department faculty but also by the U.S. Department of Energy, which viewed the facility as a national resource. Fortunately, as Department chair during the 2010s, Ronald Gilgenbach raised the private funding to renovate the Ford Nuclear Reactor building and install modern laboratories for the Department and its students, thereby preserving its national reputation and impact.

The North Campus

The Phoenix Project's laboratory, the Phoenix Memorial Laboratory, was constructed as one of the first buildings on the University's new North Campus. As the University had faced growing enrollments in the years following WWII, it soon realized that its Central Campus site was too confined by the surrounding city of Ann Arbor to accommodate significant growth. The Regents agreed in the late 1940s to acquire 300 acres of farmland across the Huron River from the University Hospital, just in case the University needed the room to expand, although at the time there had been no immediate academic objectives for the use of this space.

NE faculty 1968

NERS faculty 1988

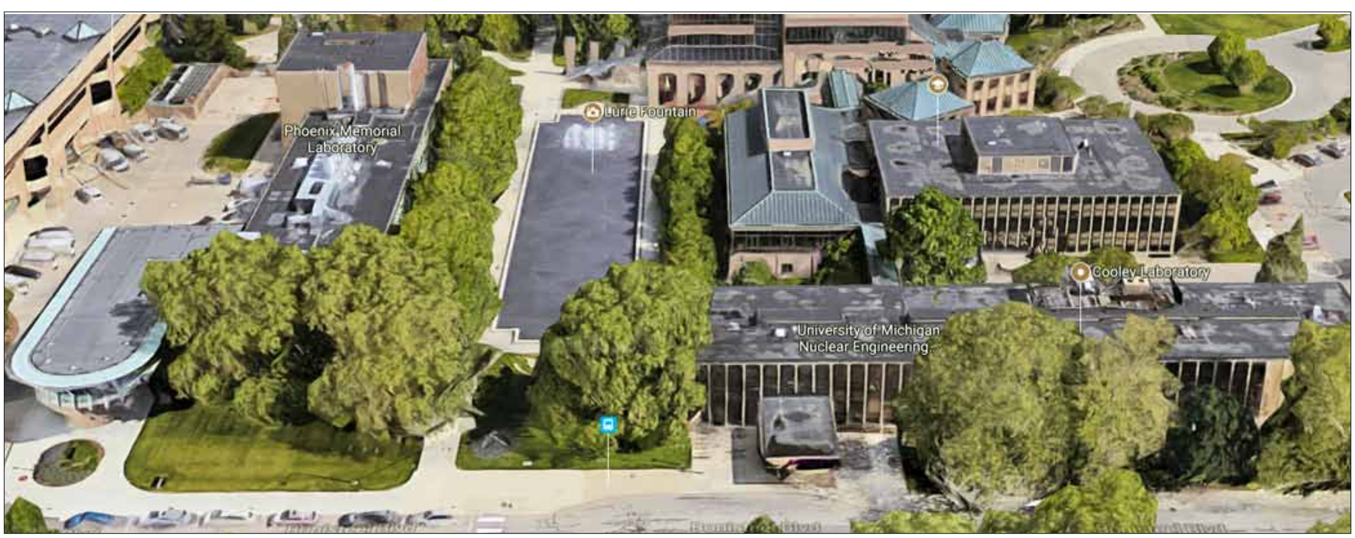
NERS faculty 2012


Phoenix Memorial Lab and Ford Nuclear Reactor


NE moves into Cooley Memorial Laboratory


Today's Nuclear Engineering Laboratory


Today's facilities



Today's NERS Department

The noted Finnish architect Eero Saarinen, son of former University faculty member Eliel Saarinen (who also was the first president of the Cranbrook Academy of Art), was retained in 1951 to develop a master plan for the site. Saarinen had recently completed the design of the General Motors Technical Center in Warren, Michigan, and his design for the University's North Campus bears a striking resemblance to this earlier project.

Although there were some early thoughts given to relocating the School of Education, Natural Resources, Music and Fine Arts to the North Campus, the construction of the Michigan Memorial Phoenix Project soon repurposed the site for engineering research and eventually the entire College of Engineering. The first buildings were the Mortimer Cooley Electronics Laboratory (1951), where much of the classified research associated with Willow Run Laboratories was conducted, the Phoenix Memorial Laboratory (1955), the Automotive Laboratory (1957), the wind tunnel and a small laboratory for Aerospace Engineering (1957), and the Fluids Laboratory (1958), later renamed the G. G. Brown Laboratory.

As enrollments continued to grow, the University launched a series of planning exercises that considered the relocation of additional academic programs to the North Campus. One plan even envisioned growth of the University to perhaps as many as 100,000 students, with the North Campus becoming one of a chain of campuses, similar in size to the Central Campus and extending to the northeast of Ann Arbor.

During the 1950s and 1960s, the University built a number of large student dormitories and married-student housing complexes on the North Campus. However, for most of this period, the Department of Nuclear Engineering was the only academic program located entirely on the North Campus, because of the proximity of the Phoenix Laboratory.

Although the College of Engineering was the first major University academic unit earmarked for moving to the North Campus, this objective was soon set aside in deference to other priorities. First, the School of Music was given a major new complex on the North Campus (1964) — its building designed by Eero Saarinen himself — followed soon afterward by the School of Architecture and Design and, later in 1974, the School of Art when it separated from Architecture. The North Campus Commons (1965), now renamed the Pierpont Commons, and the Chrysler Center for Continuing Engineering Education (1971) soon followed. The University also located other major research facilities on the North Campus, including the Cyclotron Laboratory (Physics), the Institute of Science and Technology (1963, Smith, Hinchman and Gryllis), and the Highway Safety Research Institute (1965).

These latter two research institutes are of interest, since both were strongly opposed by the College of Engineering. They, along with the Phoenix Laboratory, which also fell under University authority, represented an effort by the University's vice president for research to build major research programs, but these competed directly with the College for both state and federal funding. In each case, they led to significant weakening of the programs in the College associated with these areas.

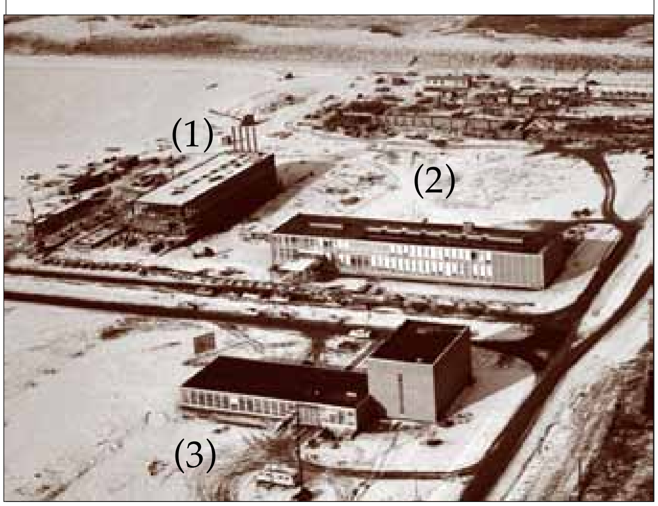
Perhaps the best illustration that the University had largely turned away from its early plans to move the College of Engineering to the North Campus is provided by the photograph on page 16, taken during the late 1970s. The Schools of Architecture and Art are clearly visible, along with the Institute for Science and Technology. And where is Engineering? This can be seen in yet another photograph, taken at about the same time, which shows only four small buildings: the Cooley Electronics Laboratory, the Automotive Laboratory, the G. G. Brown Laboratory, and a small building for Aerospace Engineering.

Farmland north of Ann Arbor

Site of the proposed North Campus

Master plan by Eero Saarinen

Early work on the North Campus



PML(1), the Cooley Lab (2), and Library Storage (3)

The Phoenix Memorial Laboratory (1960)

Early development of the North Campus

The North Campus in 1970...but where is Engineering?

Key Dates in the History of the Department

1947: First UM course in nuclear energy applications offered

1952: First graduate program in nuclear engineering in the United States

1957: Ford Nuclear Reactor, the third university reactor in the nation, achieves criticality and would operate for 46 years, until 2003. Its former containment building was rebuilt as a new Nuclear Engineering Laboratory, which opened in 2017

1958: Department of Nuclear Engineering was created as a graduate program

1965: Undergraduate program in nuclear engineering established

1970s and 1980s: Development of technology to reload similar research reactors with low-enrichment uranium

1981: Initial criticality reached for the Ford Nuclear Reactor (FNR) on low-enrichment uranium (LEU) fuel. The FNR was the first research reactor in the world to convert to LEU fuel and served as the demonstration reactor for the U.S. Reduced Enrichment for Research and Test Reactors (RERTR) initiative.

1995: Department name changed to Nuclear Engineering and Radiological Sciences (NERS)

2002: Decision to decommission the Ford Nuclear Reactor

2010: Launch of the Consortium for the Advanced Simulation of light water reactors (CASL), a U.S. Department of Energy Innovation Hub, of which UM is a founding partner

2014: Funding of the Consortium for Verification Technology, led by UM NERS

2015: Wall-breaking for construction of the Nuclear Engineering Laboratory

2017: Completion of the Nuclear Engineering Laboratory

USN&WR Quality Rankings of UM Department of Nuclear Engineering and Radiological Sciences

YEAR	Grad RANKING	Undergrad RANKING
2001	3	2
2002	3	2
2003	3	9
2004	3	4
2005	2	4
2006	1	(UG rankings cease)
2007	2	
2008	1	
2009	1	
2010	1	
2011	1	
2012	1	
2013	2	
2014	1	(tie with MIT)
2015	1	
2016	1	
2017	1	
2018	1	

Chapter 3

The 1960s: "Too Cheap to Meter"

The Department of Nuclear Engineering evolved rapidly throughout the 1960s. Nationally, optimism about the use of atomic energy to generate electricity ran high. The U.S. Atomic Energy Commission, under the direction of Chairman Lewis J. Strauss, launched a two-decade aggressive expansion of nuclear power plant construction. Strauss stated that electricity would become "too cheap to meter."

With a world-class faculty and outstanding students, the Department rapidly established itself as a national leader in nuclear science and engineering. Throughout its history, the Department has been located on North Campus, close to the Phoenix Memorial Laboratory and the Ford Nuclear Reactor. Initially, the Departmental office was located in the Automotive Laboratory, with faculty offices and laboratories also housed in the Phoenix Laboratory and the Fluids Laboratory (now G. G. Brown Laboratory).

Graduate Education

Perhaps because of the small size of the Department of Nuclear Engineering, its focus on research and graduate education (at least until an undergraduate program was introduced in the mid-1960s), and the relative young age of its faculty members in its early years, a strong community developed among and between the faculty and graduate students. Although there were the usual tensions common among new graduate students, immersed in challenging classes and facing the trauma of preliminary examinations for admission to the doctoral program, these rapidly disappeared as graduate students began to work more closely with faculty members on their dissertation research.

These close interactions contributed to the extraordinary quality of the Department's graduate students. One early incident, in particular, demonstrates how this sense of community helped grow the Department. During the 1960s, the Atomic Energy

G. G. Brown Laboratory

Automotive Laboratory

Commission (AEC) introduced a fellowship program for doctoral studies in nuclear science and engineering awarded each year to the nation's most outstanding graduate students. During its early years, one of the Nuclear Engineering department's faculty members, Paul Zweifel, served on the selection committee for the AEC fellowships. When he returned to Ann Arbor after the selection, he persuaded his colleagues to contact each of the winners and invite them on an all-expenses-paid visit to UM to meet the faculty and tour the Department. This process managed to recruit many of the top graduate students in the country that year (although drawing the ire of other nuclear engineering programs) and led to the tremendous strength of the Department's graduate program. That strength continues today, with the Department usually ranking #1 in the nation and having won over 20% of the American Nuclear Society Mark Mills Awards bestowed for the top dissertation.

Research Activities

Henry Gomberg and International Leadership

As the young Department gained momentum, Gomberg was garnering international recognition as a leader in research on atomic energy for peaceful applications. He presented two papers at the 1955 Geneva Conference on Peacetime Atomic Energy and chaired the National Research Council Committee on Research Reactors. His research at UM focused on radiation detection. With colleague William Kerr, he co-developed a nuclear reactor simulator for teaching purposes.

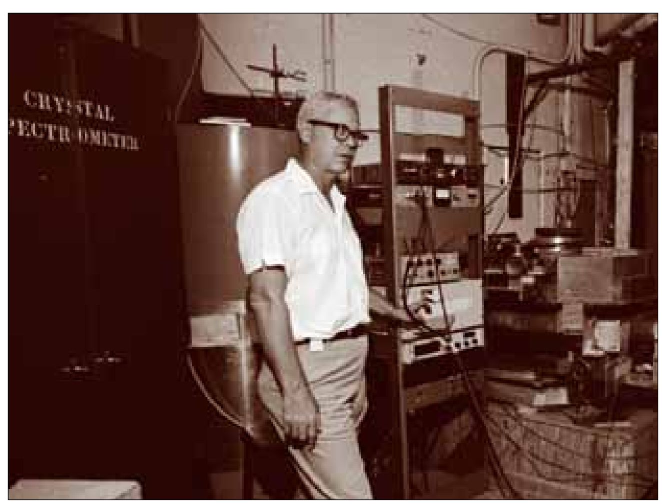
Gomberg's international prominence and activities led him to play a key role in the U.S. government's confirmation in 1960 that Israel was building a nuclear reactor capable of producing weapons-grade plutonium. Gomberg had gone to Israel as a consultant to the Israeli Atomic Energy Commission and as a result of his discussions there believed the country was undertaking a classified project in collaboration with France. He provided testimony to multiple intelligence agencies when he returned home, and his findings, along with other information, led to confirmation of the Dimona reactor, at the time under construction in the Negev desert.

In 1961, Gomberg resigned from the chairmanship of the Department and the directorship of the Michigan Memorial Phoenix Project to assume the role of deputy director of the Atomic Energy Commission's Puerto Rico Nuclear Center and physics professor at University of Puerto Rico, Rio Piedras Campus.

William Kerr and Departmental Stewardship into the 1960s

William Kerr, who had joined the Nuclear Engineering department in 1957 and was promoted to full professor in 1958, assumed the chairmanship upon Gomberg's departure in 1961. Kerr also was named director of the Michigan Memorial Phoenix

Henry Gomberg lecturing at Geneva Conference



William Kerr


William Kerr


Paul Zweifel


Richard Osborn

Project, a role he held until his retirement nearly three decades later, in 1989. Kerr served as Department chair until 1974, and his contributions during this time were instrumental in cementing the Department's early successes, developing a model curriculum and establishing UM Nuclear Engineering's reputation as one of the country's strongest.

Under Kerr's leadership, the undergraduate program in Nuclear Engineering was established in 1965. The first Bachelor of Science degrees were awarded two years later.

William Kerr's research and service centered on nuclear reactor safety. He developed a course on reactor safety that was popular with students, and he earned a national reputation as an expert and leader in the safe development of nuclear power. He served as a consultant to Oak Ridge National Laboratory in the 1950s and to the U.S. Department of State from 1956 to 1965. He was a member for over 20 years of the U.S. Nuclear Regulatory Commission Advisory Committee on Reactor Safeguards and also served as chair.

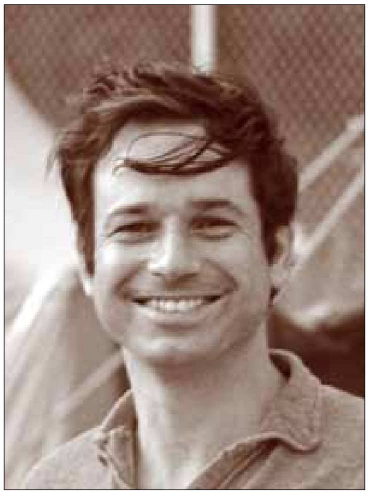
Chihiro Kikuchi and the Ruby Maser

In 1955, Chihiro Kikuchi came to UM's Willow Run Laboratories as a research physicist working to develop a solid-state maser, a microwave amplifier and precursor to the laser. The term "maser" was derived from the acronym for Microwave Amplification by the Stimulated Emission of Radiation, and these devices were of strong interest to the military for their potential as low-noise, high-sensitivity radar receivers.

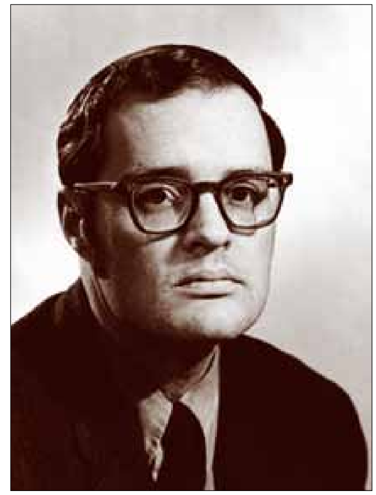
Solid-state masers offered advantages over those that used a gas (often, ammonia). According to *The History of the Laser* by Mario Bertolotti, Kikuchi was tasked with building such a solid-state maser for passive detection systems, and he investigated using pink ruby. By changing the angle the external magnetic field makes with the crystal axis, Kikuchi was able to simplify the equations and, in 1957, demonstrate the world's first working ruby maser (with samples of pink ruby obtained from the UM Minerology Department).

Kikuchi's breakthrough was made an exhibit at the Smithsonian Institution, according to Kikuchi's faculty memoir. In 1964, Bell Laboratories used the ruby maser to measure microwave radiation from Venus; the ruby


Chihiro Kikuchi and the Ruby Maser


Fred Shure


Ziya Akcasu


Louis Hamilton

maser also was used to obtain photographs during exploratory missions to Mars.

Kikuchi joined the Nuclear Engineering faculty in 1959 as a full professor. His research focused on solid-state physics, namely electron spin resonance, in addition to radiation effects in materials and fundamental aspects of materials science. He later turned his attention toward advocacy for nuclear power and policy issues related to nuclear energy development.

Theoretical Studies

One of the Department's leading theoreticians was Richard K. Osborn, who embraced cutting-edge methods to attack the most difficult of problems. Osborn had a very close relationship with the graduate students in the Department, and his door was always open to chat with interested students. He began a long-standing tradition of meeting with students and sometimes faculty colleagues at the Old Heidelberg bar in downtown Ann Arbor after each Friday afternoon seminar.

Yet another member of this group was Ziya Akcasu, a "polymath" with strong interests and remarkable talent who worked in broad areas, from reactor noise analysis to non-equilibrium statistical mechanics to neutron scattering. Both Osborn and Akcasu were considered among the very best teachers in the Department, attracting a number of outstanding students as their PhD candidates.

In 1966, Sidney Yip and his advisor and subsequent colleague, Osborn, published a monograph on The F*oundations of Neutron Transport Theory*. George Summerfield contributed to the theory of neutron transport, including proving the completeness of the half-range solutions to the linear Boltzmann equation. Akcasu investigated neutron scattering in polymers.

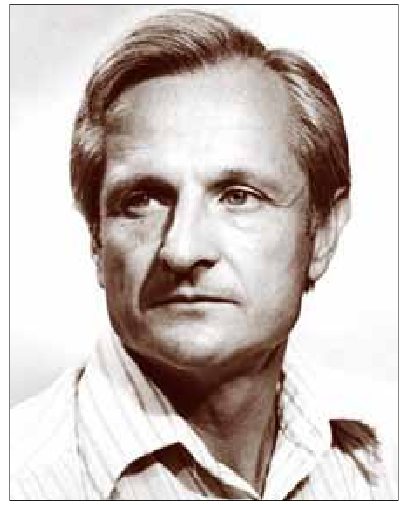
Although working most closely in theoretical support of John King's neutron scattering experiments, Summerfield was also a theoretician of high ability and broad interests. He also happened to be the leading athlete among the Department's faculty, competing frequently in track and field events at the master's level.

One of the areas of achievement during the 1960s was the development by UM physicist Kenneth Case of an exact method for solving the complex equations describing neutron transport in materials. The so-called "Case Method" was further developed by Paul Zweifel at UM through a series of doctoral dissertations, papers and eventually a textbook with Case. Fred Shure, a mathematical physicist, joined the transport theory team.

Through the 1960s and 1970s, the University of Michigan was known as the leading institution worldwide for neutron transport, with Nuclear Engineering faculty acknowledged as leaders in the field, including Zweifel, Osborn, Akcasu, Summerfield, Shure, and Duderstadt. During this time, a large number of doctoral theses were written on esoteric topics, such as half-range completeness or application to anisotropic scattering, and these students went on to

James Duderstadt

Terry Kammash



David Bach

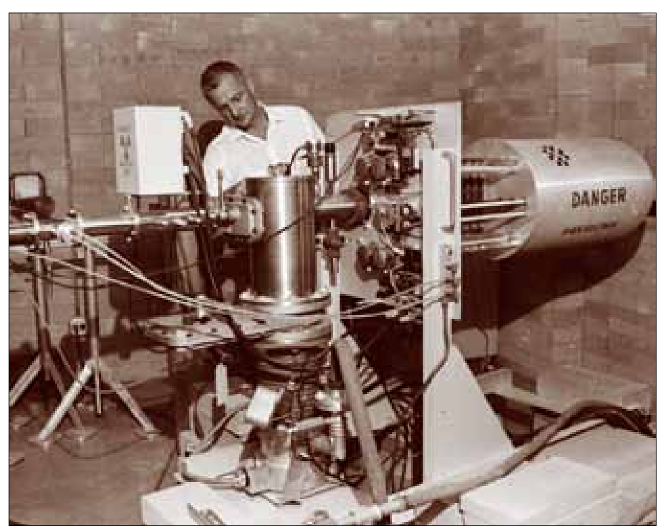
advance the field of neutron transport at universities and national laboratories.

The hiring of James Duderstadt and Louis Hamilton in the late 1960s would lead to a sea change in the recognition of UM Nuclear Engineering as a leader in theoretical transport to leadership in computational transport and reactor analysis, including deterministic transport methods and Monte Carlo methods. This shift gained momentum with the hiring of John Lee in 1974, William Martin in 1977 and Ed Larsen in 1986. Subsequent hires Alex Bielajew (1997), Tom Downar (2006), Brian Kiedrowski (2014) and Won Sik Yang (2017) have cemented NERS' reputation as the premier department for computational methods development for neutron transport and reactor physics.

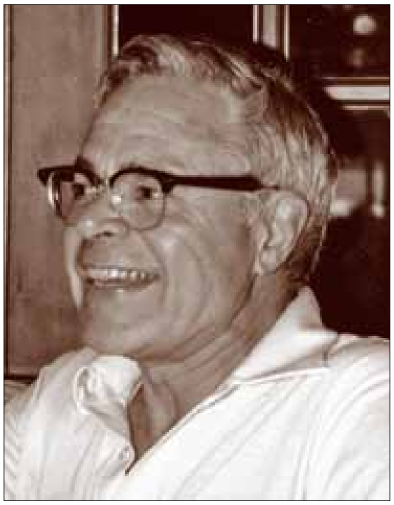
In the early 1970s, Duderstadt and Hamilton joined forces to write a textbook, *Nuclear Reactor Analysis*, which soon became the leading textbook in the field for many years. Unfortunately, Hamilton passed away in the early 1970s, although the book continues to be a part of his legacy. In fact, some nuclear programs continue to use this textbook as a reference today, almost fifty years after its first publication.

Fusion and Plasma Physics

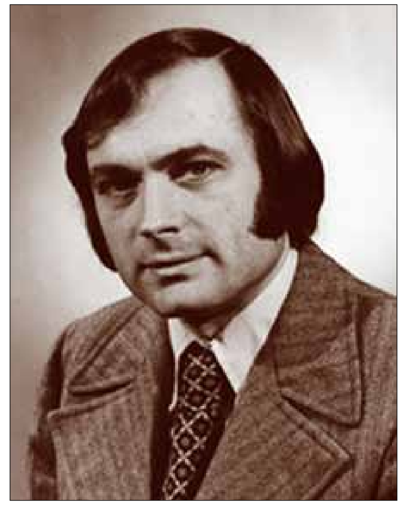
While UM Nuclear Engineering faculty were leading in the area of fission reactor analysis and radiation transport, fusion energy research was also underway by professors Terry Kammash and David Bach. Magnetic fusion was the primary research focus of Kammash (PhD '58), who joined the NERS faculty shortly after earning one of the country's first three PhDs in nuclear engineering. Prior to coming to Ann Arbor, he earned a bachelor's and master's degree in aeronautical engineering from Pennsylvania State University. His grounding in both fields gave him distinct insights into the space applications of nuclear energy, including the use of fusion energy for space propulsion. He conducted comprehensive analyses of plasma dynamics in magnetic confinement devices and identified major plasma instabilities. He wrote the first book on the subject of fusion reactor technology, entitled *Fusion Reactor Physics: Principles and Technology*, which was published by Ann Arbor Science Publishers in 1975. Kammash was appointed acting chair of the



David Bach


John King


George Summerfield


Jack Carpenterr

Nuclear Engineering department from 1976 to 1977.

Bach built a laboratory program in plasma physics that supported both magnetic fusion and inertial confinement fusion research. Richard Osborn and Ziya Akcasu provided theoretical support for these activities.

Seminal Neutron Scattering Experiments

By the early 1960s, scientists had realized that neutrons held promise for probing the structure of materials. After conducting classified research during WW II at the Johns Hopkins University Applied Physics Laboratory (APL), John Swinton King followed his mentor, physicist William Parker, to UM. King earned a second bachelor's degree in physics (his first was in political science) and a PhD in physics in 1953. King left UM to work on the Naval Nuclear Propulsion project at Knolls Atomic Power Laboratory, where he helped develop the U.S. Navy's fleet of nuclear submarines. King returned to UM in 1959 and joined the Nuclear Engineering department, where he established a world-class neutron scattering program using the Ford Nuclear Reactor.


Jack Carpenter

Jack Carpenter, former UM Nuclear Engineering graduate and professor, noted in his remarks at King's memorial service in 2007 that "John was one of the spark plugs that ignited the program in neutron scattering studies in the Department. He was a driving force in the weekly neutron scattering seminar series that ran for many years, in which both faculty and students lectured and listened and learned the field — starting with little prior knowledge."

King, too, had recalled the excitement, collaboration and sense of curiosity that permeated the Department at the time. On the occasion of the 50th anniversary of the Michigan Memorial Phoenix Project in 1999, King recounted the early years of the neutron scattering program, calling it a "wonderful confluence" of passionate faculty, visiting scientists and "remarkable" graduate students.

Several Nuclear Engineering faculty members worked closely, advancing theory and experimental techniques related to neutron scattering. King called it an "unusual collaboration" of experimentalists (King, Sam Werner) and theorists (Paul Zweifel, Fred Shure, George Summerfield, Richard Osborn, Sidney Yip, Ziya


Glenn Knoll


Dieter Vincent


Lloyd Brownell

Akcasu). It was a necessary collaboration, he said, since neutron data were complex and required theoretical calculation. Zweifel organized three international symposia on neutron scattering, and the interactions among scientists sharing new experimental methods only added to the vigor, and rigor, of the program.

King and colleagues conducted a wide range of neutron scattering experiments over the course of two decades. The impact of the neutron scattering work at UM on the field of nuclear engineering was significant, including the establishment of several physical and chemical parameters "that have withstood the test of time," King noted in his remarks in 1999. The program's experimental innovations were important contributions as well. And, as King added, "surely the greatest contribution was to give 26 great students an extraordinary education."

Nuclear Measurements

Such a remarkable graduate student was Glenn F. Knoll. Paul Zweifel was Knoll's initial advisor, but Knoll wanted to focus less on theory and more on laboratory work. Zweifel, a theoretician, recommended Knoll work with John King, "a very talented experimentalist," who at the time of their conversation was just arriving at UM. Knoll would go on to establish the field of nuclear measurements and make many other important contributions to the Department, the University and to the field of nuclear engineering.

Under King's mentorship, Knoll earned his PhD in 1963 and joined the Department as faculty. He is widely credited not only with founding the field of radiation measurement but also for his innovative approaches to radiation detector development, including the use of room-temperature semiconductor detectors. His work led to several patents related to detection and signal processing, and the high-precision neutron cross-section data generated in his laboratory over the span of 30 years have enabled further advances by colleagues and subsequent generations of investigators in nuclear physics and engineering. His contributions of new techniques for radiation imaging led to methods that have improved diagnostic accuracy and treatment for patients.

In 1964, Knoll organized the first Symposium on Radiation Measurements and Applications, or SORMA, as the multi-day event is known today, more than 50 years after its creation. The textbook Knoll authored in 1979, *Radiation Detection and Measurement,* has had major impact on the field. Now in its fourth edition (2010), the book continues to be known as an authoritative resource and is used worldwide in the fields of experimental physics, nuclear medicine and nuclear engineering.

Radiation Effects

In the 1950s, Lloyd Brownell initiated research activities on the utilization of fission products for the preservation of foods, utilizing a greenhouse built adjacent to the Phoenix Memorial Laboratory. This

The Department in 1968

work would have a significant impact on the field of food technology.

The experimental analysis of radiation effects on materials was launched by Dieter Vincent in the early 1960s, developing a collaboration with the National Bureau of Standards. Vincent's laboratory course on the analytical uses of nuclear radiation was the first of its kind. His work would stimulate a major focus of the Department on the study of radiation effects on materials in later decades.

The Transition

The early history of the Nuclear Engineering department was dominated by senior faculty members with strong leadership experience and research accomplishments, individuals such as Henry Gomberg (the founding director of both the Michigan Memorial Phoenix Project and first chair of the Nuclear Engineering department), William Kerr (also serving as both Department chair and director of the Phoenix Memorial Laboratory), John King (a solid-state physicist developing the experimental program that would enable the Phoenix Project to assume leadership in neutron scattering), Terry Kammash (one of the first Nuclear Engineering PhDs and later lead researcher in the Department's nuclear fusion and plasma physics activities for several decades), and Richard Osborn (a mathematical physicist important in the early days of radiation transport).

However, in the mid-to late 1960s, a new generation of faculty began to assert itself. This new cohort included Paul Zweifel (a mathematical physicist, noted for luring Kenneth Case from the Physics department to provide the methods to analytically solve the neutron transport equation), Fred Shure (another brilliant physicist, but also involved in starting a for-profit reactor design company, ESZ, Inc., with Milton Edlund and Zweifel), George Summerfield (a solid-state physicist providing the theoretical support for the neutron scattering experiments), Jack Carpenter (who became one of the leading experimentalists in thermal neutron scattering) and Ziya Akcasu (a theoretical physicist leading the effort in nuclear reactor noise analysis and statistics).

What's in a Name?

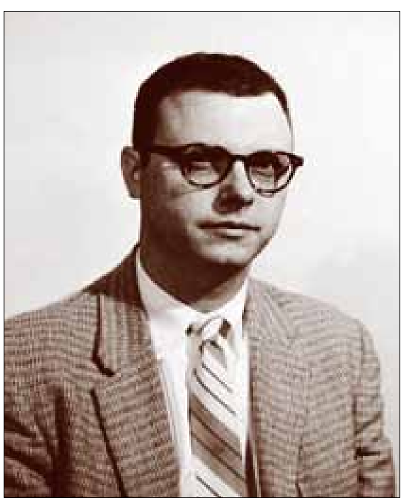
During the 1950s and early 1960s, the program was known as the Department of Nuclear Engineering. However, it granted two separate degrees: in nuclear science for those with undergraduate degrees in physics or other science, and in nuclear engineering, for those with degrees in engineering. Hence there was a tendency to refer to the "Department of Nuclear Science and Engineering," although this was not implemented through formal action. In the 1990s, the current department name, "Nuclear Engineering and Radiological Sciences", was formally adopted, reflecting the broad activities in both radiation measurements and nuclear medicine.

Henry Gomberg 1942-1967

William Kerr 1948-2010

Chihiro Kikuchi 1955-1982

John King 1959-2007

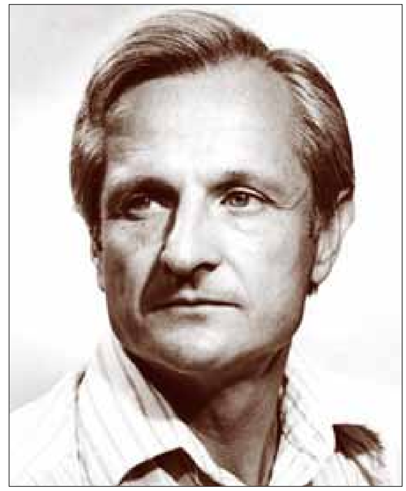


Paul Zweifel 1958-1968

Richard Osborn 1957-1986

Early Faculty Members

Glenn Knoll 1962-2000



David Bach 1964-1979

Lloyd Brownell 1942-1975

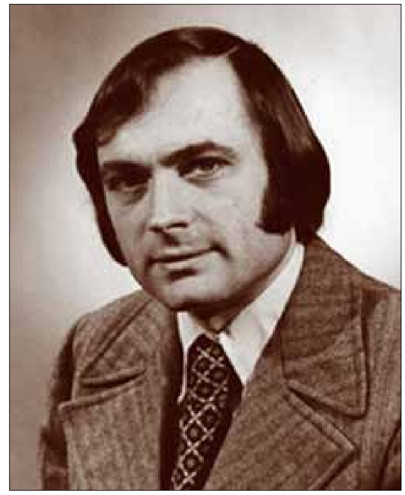
George West 1956-1970

Terry Kammash 1954-1996

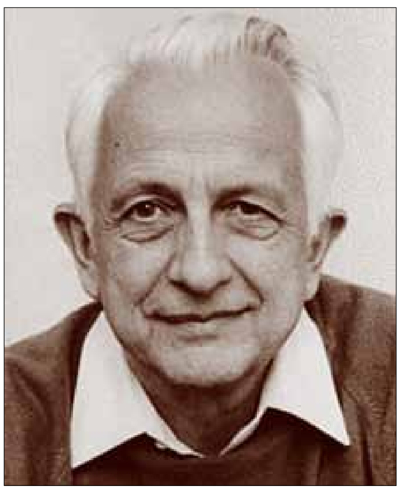
Fred Shure 1959-1984

Early Faculty Members

Ziya Akcasu 1963-1979

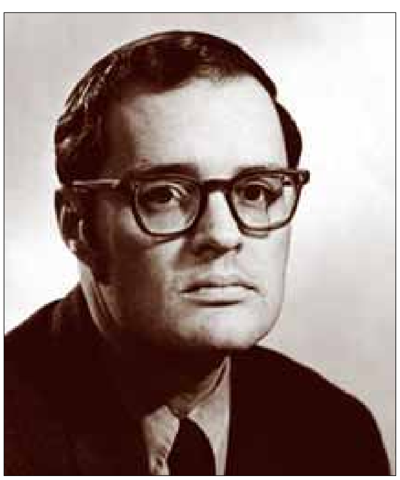


John Carpenter 1964-1975



Dieter Vincent 1960-1989

George Summerfield 1962-1998



Louis Hamilton 1968-1973

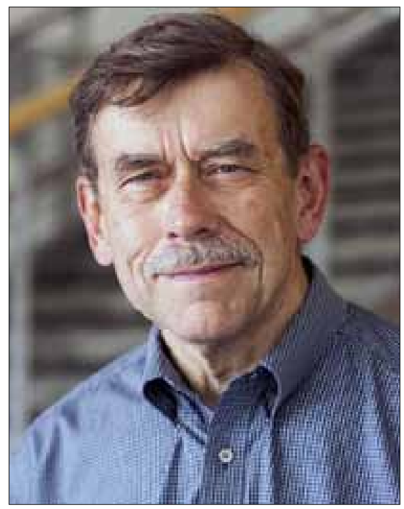
James Duderstadt 1968-present

Early Faculty Members

Harvey Graves 1968-1973

John Lee 1974-present

Ron Gilgenbach 1980-present



William Martin 1977-present

Gary Was 1980-present

James Holloway 1990-present

Faculty Members

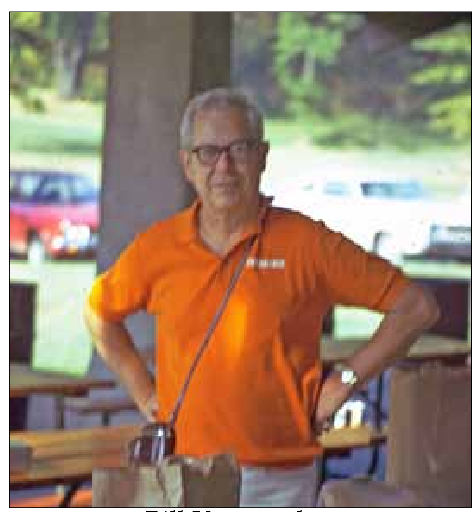
Sid Karin and Harvey Graves at the NE Picnic

Ziya Akcasu as a soccer star

Pat Shure and her children on a Homecoming float

Ellen Leonard and Richard Osborn

What's it all mean, Dr. Fleming?



Bill Kerr at play

Images from the 1960s

Chapter 4

The 1970s: Rising to Leadership

The 1970s represented another period of transition for the Department. A major relocation took place in 1977 with the move of the departmental office and most faculty offices from the Automotive Laboratory and G. G. Brown Laboratory to the Mortimer Cooley Laboratory, adjacent to the Phoenix Memorial Laboratory.

Following William Kerr's 13 years of highly successful leadership as chair of the Department of Nuclear Engineering and also as director of the Michigan Memorial Phoenix Project, the Department was fortunate to convince one of its most valuable faculty members, John King, to serve as Kerr's successor as chair. King would not only provide outstanding leadership as chair, but he also would continue to shine as one of the most prominent researchers and teachers in the Department during this period. He was widely known by the Department faculty as a true "gentleman and a scholar."

Chairman John King
1974-1979

A dinner to honor the outgoing chair (left to right)
Ron Fleming, Ruth Kerr, Bill Kerr,
Helen Lum, Melahat Akcasu, Ziya Akcasu

The Department Moves into New Quarters

During the 1950s and 1960s, the Department's faculty and students had been divided between two buildings on the North Campus: the G. G. Brown Laboratory and the Automotive Laboratory. Not only did these two physical locations divide the activities of the Department, but both buildings also were situated some distance from the Phoenix Memorial Laboratory, where much of the experimental work of the Department occurred. While there was considerable discussion about the need to consolidate, little happened until one night when Ron Fleming, then a graduate student, went on a "midnight reconnaissance mission" and found that much of the space in the Cooley Laboratory was empty because a great deal of the electronics research activity that took place there had been transferred to the Willow Run Laboratories.

Department leadership quickly realized this would make an ideal location for the Department, both because there was sufficient space to accommodate all of the faculty and students and also because an underground connector linked Cooley with the Phoenix Laboratory. In addition, the Cooley Laboratory was outfitted not only with classrooms but also a large lecture hall for major presentations.

The faculty of the Department, led by Chairman John King, made a strong case to Dean David Ragone for the move, and the College of Engineering agreed. This consolidated the Department of Nuclear Engineering in the Cooley Laboratory, where it has been located for the past four decades.

At the same time, several laboratories not located in the Phoenix Laboratory were transferred to the large shielded bays that formerly housed the Physics department cyclotrons. The Nuclear Engineering department's research laboratories in the former cyclotron bays evolved into the Michigan Ion Beam Laboratory, Neutron Science Laboratory and the Plasma, Pulsed Power and Microwave Laboratory, occupying Radiation Sciences Labs #1 and #2 connected to the Naval Architecture and Marine Engineering building.

Activities in the 1970s

Building upon the strong foundation laid in the late 1950s and 1960s, neutron scattering research continued its forward momentum in the 1970s and further reinforced the national prominence of the UM Nuclear Engineering department.

The COW Experiment: Gravitationally-Induced Quantum Interference

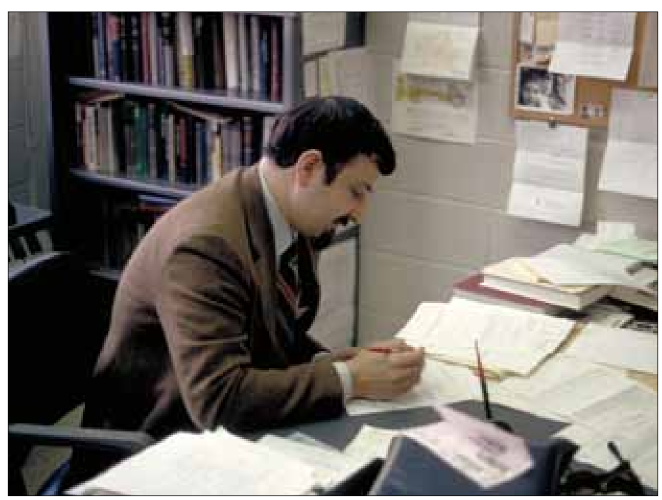
Much as Glenn Knoll is credited with estaablishng the field of nuclear measurements, alumnus Sam Werner, who earned his PhD in Nuclear Engineering from UM in 1965, helped establish the field of neutron interferometry. After earning his degree, Werner went to work for the Ford Motor Company Scientific Laboratory in Dearborn, and he spent a great deal of time in Ann Arbor working at the Ford Nuclear Reactor to investigate the magnetic properties of materials.

Werner worked with two colleagues, Al Overhauser and Roberto Colella, both on the faculty of Purdue University. The team designed an experiment to explore the effects of gravity on neutron de Broglie waves using a neutron interferometer with parallel blades cut from a perfect silicon crystal. Werner recalls that some of their colleagues were skeptical; even he wasn't sure their experiment would work.

It did, and Colella, Overhauser and Werner were the first in the world to observe the effects of the Earth's gravity and rotation on quantum interference. This was the first experiment — dubbed the "COW experiment" after the researchers' initials — in physics in which gravity and inertia could be interpreted as quantum mechanical phenomena.

Neutron interferometry is now a mature technique and the preferred method for measuring neutron-nuclear scattering lengths, which are used in nuclear physics, nuclear engineering, solid state physics and materials science. The technique Werner pioneered has opened up other research areas as well, including atom beam interferometry.

The COW Team: Colella, Overhauser, and Werner



Glenn Knoll at work

Cooley Memorial Laboratory

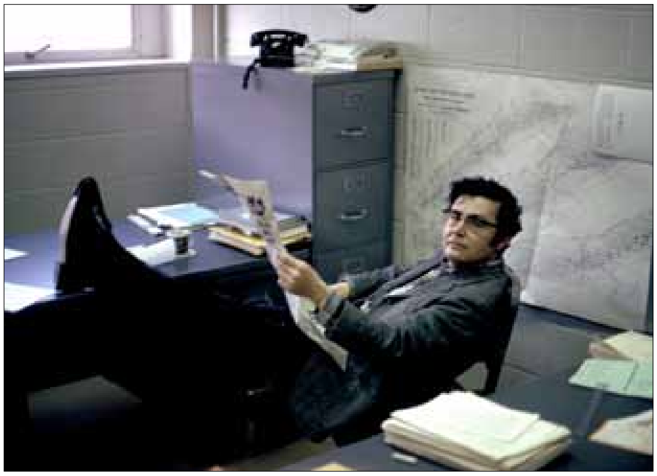
Nuclear Engineering's New Home

Neutron Science Laboratory

Plasma Pulsed Power and Microwave Lab

Michigan Ion Beam Laboratory

The Department moves into new space!


Ziya Akcasu deep in thought


Bill Martin with student Marvin Adams

Coinciding with the 40th anniversary of the COW experiment, Oxford University Press released the second edition of the book Werner co-authored with colleague Helmut Rauch, *Neutron Interferometry: Lessons in Experimental Quantum Mechanics*. Rauch conducted the world's first neutron interferometry experiment in Vienna in 1974.

Nuclear Reactor Analysis

William Martin (PhD '76) joined the Department the year after earning his doctorate. Martin's research focused on developing numerical methods for application to nuclear engineering problems and was one of the first to employ vectorized Monte Carlo techniques to radiation transport. The improved Monte Carlo methods he developed contributed to more accurate analysis of nuclear reactors and reactor plant simulation. With Jim Duderstadt, who was promoted to full professor in 1975 after joining the faculty in 1968, Martin co-authored the book, *Transport Theory*, published in 1979 (Wiley - Interscience). In 1971, Ziya Akcasu also published a textbook, *Mathematical Methods in Nuclear Reactor Dynamics* (Academic Press).

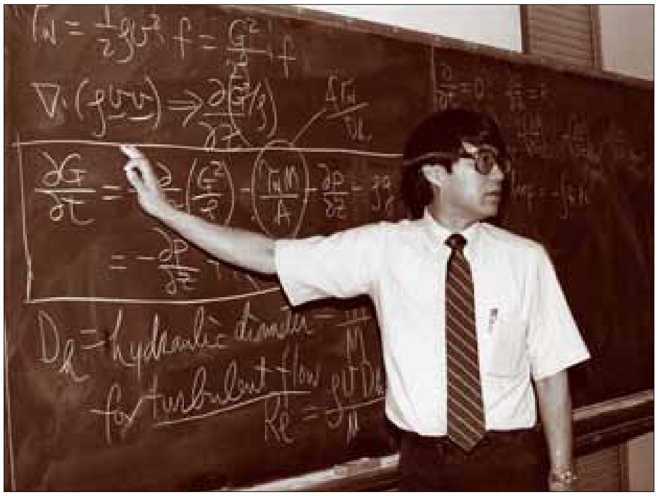
John Lee's research programs during his tenure at UM from 1974 to the present have covered broad areas of nuclear reactor physics and engineering, reflecting five years of employment in the nuclear industry that preceded his academic career. One of his early projects involved development of numerical methods for transient thermal-hydraulic analyses of nuclear plant systems focusing on steam generators and associated equipment. This project involved participation by Akcasu, Martin and Duderstadt. Production software featuring non-equilibrium drift-flux algorithms was developed and marketed as the TRANSG code, under The auspices of the Electric Power Research Institute,. which became an important resource for the analysis of nuclear reactor transients and safety.

Lee's research in nuclear reactor physics and system analysis included space-time reactor kinetics studies that form a basis for systematic load-follow maneuvers in pressurized water reactor plants. His surveillance of nuclear system degradations and the quantification of system reliability have been important resources for the nuclear power industry. Lee's efforts in reactor safety research were reflected in the 2011 publication of the textbook, *Risk and Safety Analysis of Nuclear Systems.*

Reducing the Risk of Proliferation:
Low-Enrichment Uranium Demonstration Project

The Department played a key early role in a high-visibility nuclear nonproliferation project in the 1970s and 1980s. The Reduced Enrichment Research and Test Reactor (RERTR) Program was run by Argonne National Laboratory for the U.S. Department of Energy. Its primary goal was the conversion of research reactors that used weapons-grade, highly-enriched (over 90%) uranium (HEU) fuel to low-enriched uranium (LEU) fuel not suitable for use in a nuclear weapon.

In 1979, the Ford Nuclear Reactor was fueled with



John Lee

Bill Martin

HEU fuel. Argonne approached William Kerr, who was head of the Phoenix Project at the time and asked if UM would agree to let the Ford reactor serve as the demonstration research reactor for the conversion from HEU to LEU fuel. Kerr became the principal investigator for a multi-year research project to design and analyze the LEU core and carry out the conversion of the Ford reactor to LEU fuel. This research project included Department faculty members John King, John Lee and William Martin as well as future faculty member David Wehe. The conversion included necessary neutronic and thermal-hydraulic analyses to ensure the Ford reactor satisfied all its safety and operational specifications.

The redesigned reactor reached initial criticality with a full LEU core in December 1981, and the conversion was complete in 1984, when the last HEU fuel element was discharged from the reactor. This was the first demonstration of a conversion from HEU to LEU fuel in a university research reactor, and it was achieved safely, with negligible impact on experimental utilization. The UM group's success had a tremendous impact on the country's, and the world's, future nonproliferation efforts.

Laser-Driven Thermonuclear Fusion

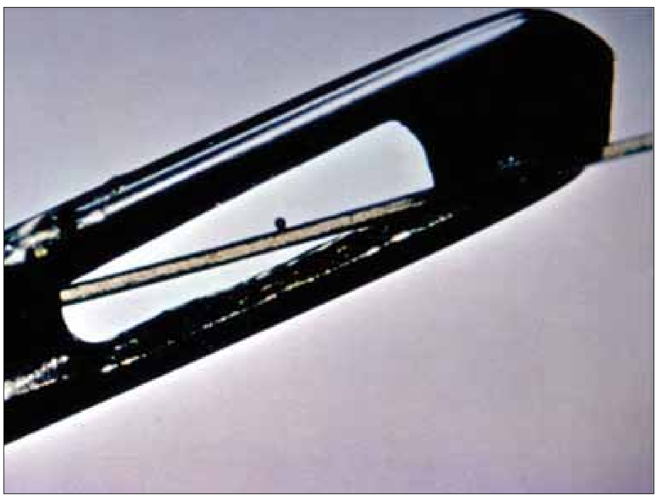
In the early 1970s, the Department became involved in a new nuclear technology utilizing high-powered lasers to compress small pellets of nuclear materials (such as deuterium and tritium) to temperatures and densities sufficient to ignite thermonuclear reactions. Jim Duderstadt first became involved with this technology, referred to as laser-driven fusion or inertial confinement fusion, during a summer spent at the Lawrence Livermore National Laboratory, where it was the basis for highly classified theoretical and experimental studies. However, at roughly the same time, a UM professor and entrepreneur in electrical engineering, Keeve (Kip) Siegal, collaborated with a former Atomic Energy Commission (AEC) physicist Keith Brueckner with the aim of turning laser-driven fusion into a practical approach for generating power (with the claim by Siegal that they planned on having an operating laser fusion power plant within 10 years). A company, KMS Fusion, was launched in Ann Arbor for this purpose, and a large laser developed by the French was flown over (in a Boeing 747) to enable further experimentation. Richard Osborn joined in the KMS effort. Although Duderstadt was also working in this area (and soon to publish a book with a former student Greg Moses on the subject), his security clearance at the AEC laboratories prevented him from even discussing the subject with Osborn. The KMS Fusion effort failed, and laser fusion remains the subject of very expensive experimentation at Department of Energy laboratories today rather than a viable power-producing technology.

Fun and Games

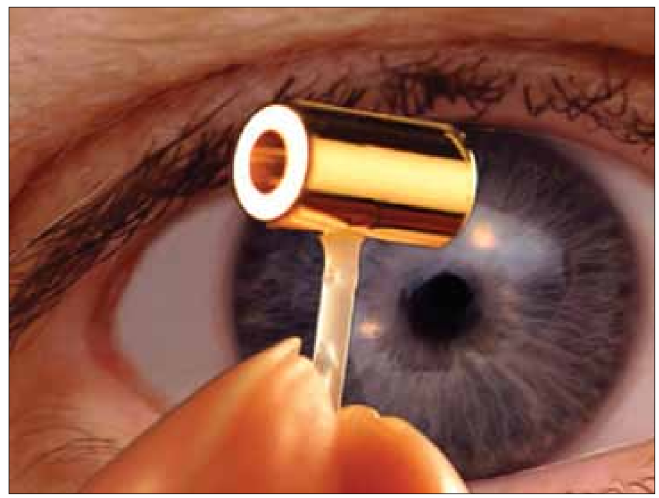
It wasn't all hard work, and the Department was a collegial one. Faculty members teamed up with graduate students for many activities, including sports — the

Lawrence Livermore Laboratory in the 1970s

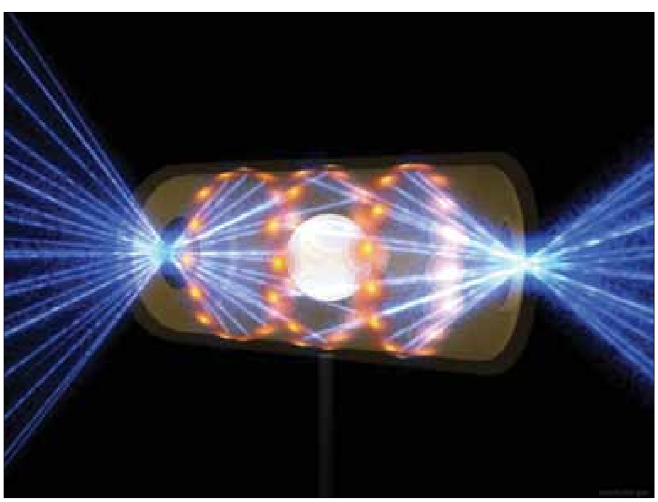
The Shiva Laser



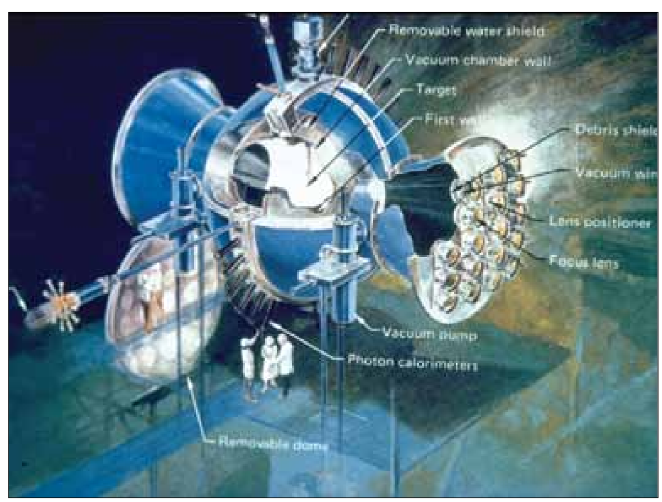
A D-T Pellet...on a human hair....in needle



The target cavity containing the fusion pellet

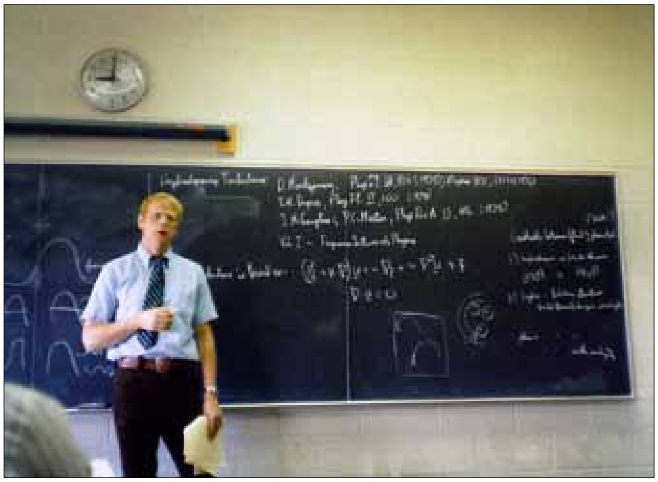


Creating an X-Ray Holrum to compress the pellet



The target chamber for the laser fusion process

Jim Duderstadt's laser fusion experience in Q Division at Lawrence Livermore Laboratory



Jim Duderstadt teaching laser fusion

Dick Phillips, Dan Atkins, Bill Podesta, Jim Duderstadt, and Steve Jobs launching the Computer Aided Engineering Network (with Apple II computers)

"Nuclear Nine" baseball team and the "Fission Five" basketball team, tennis and racquetball — and monthly poker games. In fact, the Nuclear Nine, led by Glenn Knoll, frequently was a city champion. That's primarily because one of its auxiliary players, Bill McKeachie, one of the nation's leading psychology professors, was also one of the state's most outstanding softball pitchers. Knoll had a reputation as a racquetball player, too, although rumor had it he sought out new graduate students unfamiliar with the sport and enjoyed beating them until they developed sufficient skill to hold their own. The monthly poker games usually went late into the evening, liberally lubricated with beer and the antics of "Up-a-Nickel" George Summerfield, who never refused a bet.

About the time Duderstadt assumed the College of Engineering deanship in 1981, personal computers were introduced, beginning with the Apple II running on AppleSoft BASIC. At one of these late-night poker games, Duderstadt used an Apple II to demonstrate the power of the VisiCalc spreadsheet program, the forerunner of Micorsoft's Excel. VisiCalc allowed him to process various College faculty compensation scenarios and conduct a market analysis while serving on the Provost's Budget Priority Committee. He was eventually able to obtain salary increases of 30% or more for the College of Engineering faculty in 1981.

In the mid-1980s, Glenn Knoll asked John Lee to accompany him to a Computer Sciences seminar to be given by Knoll's son, Tom, where some of the initial ideas for high-fidelity 3-D image processing software were discussed as part of his doctoral dissertation research. Soon after, at a departmental reception at his home, Tom Knoll showcased an early version of Photoshop, which was acquired by Adobe in 1988.

Back in the late 1970s, when most of the young faculty members had their offices in the G. G. Brown Laboratory (called "G. G. Frogg" by the students because of its, and several other NERS laboratories', bright green windows), faculty office doors were occasionally festooned with colorful caricatures that were apparently drawn by one of the early-riser faculty before the secretarial staff showed up at 8:00 a.m. On one of those early morning occasions, cement blocks were piled up from floor to ceiling in front of Glenn Knoll's door. Nobody remembers now why Knoll had to borrow Duderstadt's office for the day, or who eventually removed the cement blocks (fortunately, they were not lead bricks, although there were plenty of those in the building). Those were the "good old days," before Duderstadt moved his office to the Fleming Building, where he had three teams of secretarial staff supporting his 100-hour workweeks as provost and then president.

The fun times augmented research collaboration and led to lifelong friendships between faculty members and graduate students. Perhaps these strong relationships were not surprising given the intensity of the research and sense of community, which contributed to the Department's ability to attract many of the most outstanding graduate students in the world, who would later go on to distinguished careers of achievement and leadership.

The North Campus Move...At Least a Beginning

In the 1970s, College Dean David Ragone was given the mandate by University President Robben Fleming to launch a major fundraising campaign that would be key to completing the move of the College to the North Campus. The University offered the following challenge: If the College would raise $12 million in private support for the North Campus complex (of a $20 million total campaign goal), the University would seek an $18 million match from state funds to build a four-building complex. The complex would be sufficient to move all engineering departments to the North Campus.

Perhaps not surprisingly, there was considerable sentiment within the College against completing the North Campus move. Although the deteriorating quality of space in the West and East Engineering buildings on Central Campus was a major concern, many faculty members believed it important to remain in renovated space on Central Campus, close to their colleagues in Literature, Science, and the Arts (LS&A), particularly in physics, chemistry and mathematics. Furthermore, many faculty members and students enjoyed the ambiance of the South University area and worried about the detached, sterile character of (at the time) the sparsely populated North Campus. Ragone and his colleagues in the College administration dismissed these concerns, arguing that the interaction among the College and other Central Campus programs had been quite modest, and the isolation on the North Campus was a necessary inconvenience for obtaining higher quality space.

With four new buildings on the drawing boards, and a major fundraising campaign in the works, there was optimism on the part of the University administration that the College would finally compete its three-decade quest to move to the North Campus by the end of the 1970s. In fact, when new engineering faculty members were hired in the 1960s and 1970s, they were told to be sure to find a house near the North Campus so they would not have to drive too far to work. Most new faculty were wise enough to ignore this advice and instead purchased homes near the best schools, recreational and commercial centers located elsewhere in Ann Arbor.

Although the campaign was launched with a flourish, the deepening recession soon slowed activity to a crawl. After several years it became apparent that only a miracle would save the fundraising effort from embarrassment. Two of the true angels of the University, Dr. Harry Towsley and Margaret Dow Towsley, came to the rescue. The Towsleys had long been among the University's most generous donors, and after a visit by Ragone, they contacted the Dow family and arranged for a $5 million gift to fund the construction of a new building on the North Campus for Chemical and Metallurgical Engineering. The building was named the Herbert H. Dow Laboratory.

The trials and tribulations of the North Campus move were made even more difficult by the decision of the University's central administration to bump the Replacement Hospital Project ahead of Engineering in priority for state funding — essentially backing away from its earlier commitment to Ragone. Although the Michigan Legislature passed a resolution in 1977 stating it would fund 60% of the $30 million project when the College had raised its $12 million, the University pushed this aside and instead sought a state contribution of $180 million toward the $300 million hospital construction project, a project second in magnitude only to the Mackinac Bridge in the State's history. Not surprisingly, this mammoth request not only sidetracked the Engineering North Campus projects but effectively eliminated all state support for University capital projects for almost a decade.

With inflation rapidly eroding the funds raised during the campaign, the College decided to direct the entire amount (and then some) to the construction of the Dow building and defer the rest of the four-building project indefinitely.

Hence the College approached the 1980s with only a very modest beachhead on the North Campus: several research buildings, the Phoenix Memorial Laboratory and the Institute for Science and Technology (both of which in fact reported to the University Vice President

The new NERS chairman: Glenn Knoll
1979-1990

Department Chairs of NERS

Henry Gomberg (1958-1961)
William Kerr (1961-1974)
John King (1974-1979)
Terry Kammash (Acting) (1970-1977)
Glenn Knoll (1979-1990)
William Martin (1990-1994)
Gary Was (1994-1999)
John Lee (1999-2004)
William Martin (2004-2010)
Ronald Gilgenbach (2010-2018)

for Research rather than the College), a modest concrete block building for Aerospace Engineering, another small building for the water resources program and the construction site for the Dow building.

The Department of Nuclear Engineering would continue to be the only department in the College of Engineering to be entirely located on the University's North Campus until the College officially moved in the 1980s.

A New Chairman

After a decade of strong leadership, John King stepped down as chair in 1979, and Glenn Knoll took over the position.

A side observation: Knoll also would assume the role of interim Dean of Engineering from 1995 to 1996. Later, two other Department faculty members, William Martin and Gary Was, would go on to serve as associate deans, too. And, of course, Duderstadt served as Dean of Engineering during the early 1980s.

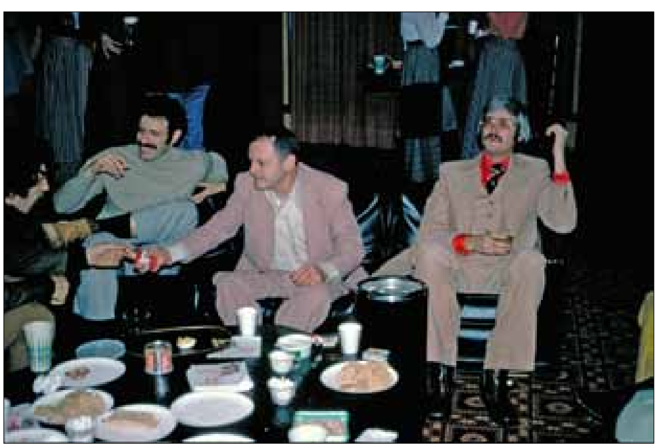
Hence the puzzle: How many nuclear engineering faculty members does it take to fill the dean's office? Answer: We don't know yet!

A fairwell to John King as NE department chair

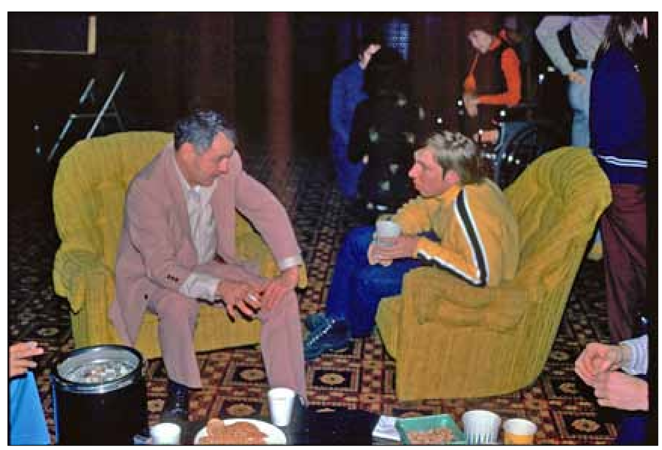
The new chair, Glenn Knoll, is given a T-shirt

Knoll is also welcomed by John King with laughter

Bill Martin would be next...

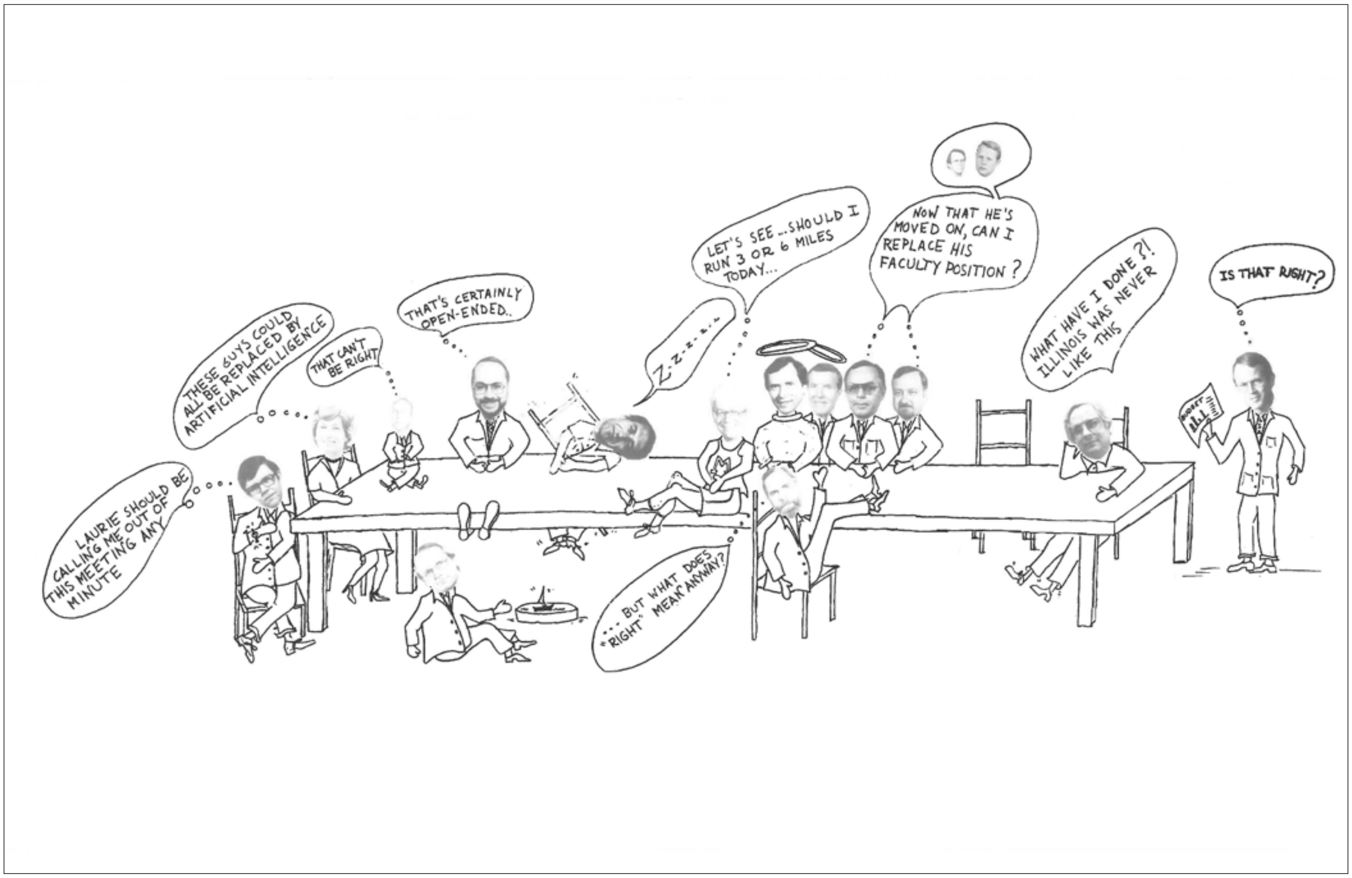


Dick Osborn with Ron Adler and Greg Moses



...and Paul Rocket

A Transition in the Nuclear Engineering Department Chair



A cartoon given to Glenn Knoll depicting his life as Dean of the College of Engineering in 1995-1996 (with photos of his colleagues from left to right: Dan Atkins, Lynn Conway, Jim Duderstadt (fading away), Scott Fogler, Ron Gibala, John Wiley, Dick Sonntag, Glenn Knoll, Chuck Vest, and below the table, Mike Parsons and Steve Pollack.

Chapter 5

The 1980s: A Maturing Program

By the early 1980s, the growth in nuclear power plants around the United States that had taken place during the 1960s and early 1970s had slowed due to a number of factors. The accident at the Three Mile Island reactor in Pennsylvania in 1979 punctuated the declining trend. Dozens of orders for new reactors were cancelled, and only a few reactors would be approved for construction during the next three decades. Still, the country had over 100 operating reactors generating some 20% of its electricity, fueling the need to investigate whether the licenses, and lifetimes, of existing operating reactors could be extended safely.

Activities

Engineering Physics and Applied Physics

Teaching and research in the Department began to diversify significantly outside the traditional nuclear engineering disciplines in the 1980s, expanding into plasma physics, materials science, radiation measurements, radiological health and medical physics. A second undergraduate program, Engineering Physics, was formerly known as Science Engineering and, in 1980, was instituted under the auspices of the Nuclear Engineering department. Later, while serving as dean, Duderstadt worked with the College of Literature, Science, and the Arts to create a new Applied Physics program to further connect the efforts of faculty and students on the North and Central campuses. This program has grown rapidly over time, knitting together graduate programs of both engineering and physics.

Advancing Plasma and Pulsed Power Research

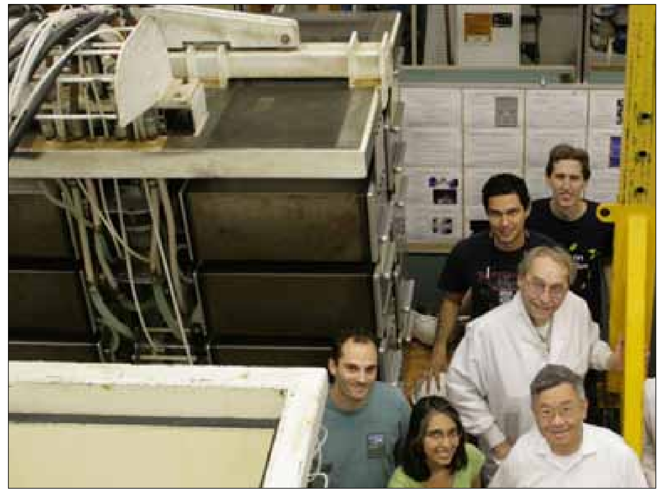
When President Ronald Reagan announced plans in 1983 for the Strategic Defense Initiative (SDI), a proposed missile defense system commonly called "Star Wars," billions of dollars were earmarked for research. The Department received significant funding for its active research programs in accelerator physics, intense electron beams and high-power microwaves. Ronald Gilgenbach, who had joined the UM faculty in 1980, received one of the first three contracts at UM, funded by the U.S. Office of Naval Research.

Research funding under this program was not without controversy, but as Gilgenbach explained in the January/February 1986 issue of *Michigan Alumnus*, the line between politics and research was a clear one. "It is not my job to relate this [research] to a strategic defense system. My job is to uncover the basic laws of nature that govern the situation. The important thing to keep in mind when doing basic research is that one cannot mix politics or emotionalism with that. The basic laws of nature are the same regardless of who the funding agency is."

Gilgenbach founded the new Intense Energy Beam Interaction Laboratory in the lab previously occupied by the Physics department's 55-inch cyclotron (Radiation Sciences Lab #1). Starting with some equipment left in the laser-plasma lab of David Bach in the G.G. Brown Laboratory, the new lab included a 12 J, 100 ns, TEA CO2 laser and a 100 kA helium Z-pinch plasma confinement device.

The goal of the new laboratory was to extend the historic leadership of the Department in laser-plasma interactions to electron beams and accelerator science. With U.S. Department of Defense support, a new accelerator facility was built, the Michigan Electron Long Beam Accelerator, or MELBA as it was called, which operated at parameters of 1 MV, 10 kA, at 1 microsecond pulse length, the longest intense electron

Ron Gilgenbach as a new NERS faculty member



The MELBA team with Y.Y. Lau and Ron Gilgenbach

beam produced at any university in the United States.

Electron beam propagation experiments coincided with the start of the SDI, and the Office of Naval Research funding supported the lab's research, including pioneering long-pulse electron beam diode experiments, the first microsecond electron beam propagation in a laser-ionized channel and the first passive-cavity stabilization of the beam-breakup instability.

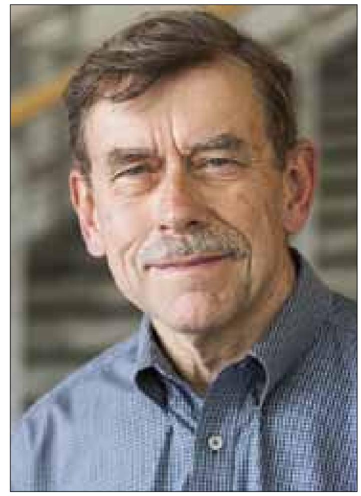
Y.Y. Lau joined the Department and the Intense Energy Beam Interaction Laboratory in 1992, providing theoretical leadership for laboratory experiments. Starting in the late 1990s, MELBA research shifted to high-power microwave generation funded by the Air Force Office of Scientific Research, first with gyrotrons and more recently on relativistic magnetrons. A notable achievement included the invention and experimental demonstration of a low-noise magnetron (two patents in 2005). A patent was issued in 2014 to Gilgenbach, Lau and three collaborators for a new type of high-power microwave magnetron.

The laboratory was renamed the Plasma, Pulsed Power and Microwave Laboratory in the late 1990s. A series of Z-pinch systems were developed, starting with the 100-kA gas Z-pinch. In 2005, a proposal was funded by Sandia National Laboratories to acquire a 1-MA Linear Transformer Driver (LTD) from the Institute of High Current Electronics in Tomsk, Russia. Gilgenbach traveled to Tomsk in 2006 for testing of the LTD, which arrived at its new home at UM in 2007, making it the first of its kind in the United States. The LTD has since been developed into a 1-MA Z-pinch experiment utilized to study the magneto-Rayleigh-Taylor and electrothermal instabilities.

Y. Y. Lau was active in the theory of electron beam, coherent radiation sources, plasmas and discharges. He revolutionized the theory of multipactor discharge, a phenomenon that leads to signal distortion in satellite communication, and to damages in microwave components in other applications using microwaves. One microwave source is the magnetron, employed in all microwave ovens. Lau co-invented a low-noise magnetron which could reduce the interference with wireless communication. He also co-invented a magnetron upgrade for applications that require high-power microwaves. The recirculating planar magnetron is capable of generating one million times the microwave power of the oven magnetron. Lau provided substantial generalization of the so-called "Child-Langmuir Law," a fundamental law on the maximum current that can flow in a diode. His generalization is to multi-dimensions, to time domain solutions, and to quantum diodes of nanometer size. He resolved the outstanding puzzle on the persistence of the helical features that were observed in the magnetized inertial fusion experiments conducted at Sandia National Laboratory. Experiments on this helical instability, and on magnetrons and on multipactor, were conducted in Gilgenbach's laboratory. (A web search of "Child-Langmuir Law" and "multipactor" would show extensive references to Lau's papers on these topics.) Finally, Lau greatly extended the theory of contact

Y. Y. Lau

Gary Was



Bill Martin

resistance. Poor contacts account for 40 percent of all electrical/electronic failures, ranging from small-scale consumer electronic devices to large-scale military and aerospace systems. His work is becoming increasingly important in the miniaturization of electronic devices.

Ion-Solid Interactions

Down the hall from the Plasma, Pulsed Power and Microwave Laboratory, Gary Was (BSE '75) was advancing the scientific and engineering communities' understanding of ion-solid interactions since establishing the Michigan Ion Beam Laboratory MIBL) in 1986..

Was' vision at the time was a university laboratory for surface modification and analysis that could provide students and faculty across the University an experimental user facility on par with those they might find at the country's national laboratories. He wanted his students, in particular, to have access to a facility that would support and enable groundbreaking research. And since many Nuclear Engineering students joined, and continue to join, national laboratories after graduation, he wanted them to know their way around such a setting. He also developed several courses that expanded the Department's offerings in ion-solid interactions, including NE 521: Radiation Effects in Materials, first offered in 1981; NE 522: Nuclear Fuels, first offered in 1982; and NE 622 Ion Beam Modification and Analysis of Materials (1986).

In the 2000s, Was expanded the Michigan Ion Beam Laboratory to proton irradiation use to emulate

Michigan Ion Beam Laboratory

the irradiated microstructure and properties of stainless steels used in nuclear reactor cores and, the following decade, established the capability of heavy ion irradiation to replicate the microstructure of materials used in fast reactor cores subject to high radiation doses. Was built the MIBL facility piece by piece in the mid-1980s, acquiring a first accelerator from Argonne National Laboratory. He soon acquired a second accelerator and several implanters. In the ensuing years, he pioneered novel techniques to control dose, temperature and the environment to an unprecedented degree. He also made a number of other important contributions. In the 1980s, he developed a thermodynamic and kinetic model for the process of sensitization in alloys used in reactor steam generators, providing the capability to understand and predict degradation of materials in reactors. This work led to first-of-a-kind experiments in the 1990s to establish that selective internal oxidation is the mechanism behind intergranular stress corrosion cracking of nickel-base alloys in the extreme environments of nuclear reactor cores. Over the years, MIBL has been expanded to include three accelerators and multiple beam lines and stations, providing unprecedented capability to emulate radiation damage in reactors. The laboratory has been recognized by the Nuclear Science User Facility program of the U.S. Department of Energy as the top ion beam laboratory in the United States among 16 facilities, including eight from national laboratories.

In 2007, Springer published Was' comprehensive graduate textbook on radiation effects in metals, *Fundamentals of Radiation Materials Science: Metals and Alloys*.

Building Infrastruture for High Performance Computing

In 1984, the National Science Foundation (NSF) announced a high-performance computing initiative and invited proposals from universities to establish centers that would provide access to supercomputers for researchers in academe as well as national laboratories and industry. At the time, the University of Michigan was operating the highly-regarded time-sharing Michigan Terminal System (MTS) with an IBM mainframe. William Martin, along with colleagues in Mathematics and the UM Computing Center, was a key participant in a UM proposal that was based on using a Fujitsu supercomputer with the IBM time-sharing operating system, allowing users from around the country to access the supercomputer. Because of its record of achievement providing time-shared computing to a large user base and the technical excellence of the Fujitsu mainframe, the UM proposal was competitive and made it to the site selection stage. Since part of the motivation for the NSF initiative was to enhance the U.S. supercomputer industry, the UM proposal, being based on a Japanese supercomputer, was not selected for funding. However, as a result of its competitive proposal, the University decided to invest resources in scientific computing, including the hiring of consultants who could help scientists access and utilize supercomputers for their research.

The College of Engineering also recognized the importance of scientific computing and funded an initiative to bring in outstanding faculty who had track records in this growing field of scientific endeavor. As part of this initiative, the Department made an offer to Edward Larsen, a leader in the field of computational neutron transport. He joined the faculty in 1986.

The growing importance of scientific computing to complement the conventional areas of theory and experiment was becoming apparent across the United States, with well-funded NSF supercomputing centers at the University of California San Diego (UCSD), University of Illinois Urbana-Champaign and later the University of Pittsburgh. University of Michigan administrators decided to create a unit in Ann Arbor that would attract faculty with common interests in scientific computing who could go after funding and bring in computing resources. Martin was a natural choice to lead this effort and, in the late 1980s, became the founding director of the UM Laboratory for Scientific Computing (LaSC).

With colleague John Boyd of Atmospheric, Oceanic and Space Sciences (AOSS; today called the Department of Climate and Space Sciences and Engineering), Martin helped initiate a unique, and widely emulated, doctoral program in Scientific Computing. The program was, and continues to be, based on the principle that scientific computing is an enabling technology and not a discipline in its own right, so students who elect

Mary Brake

David Wehe

Edward Larsen

this program must first have a home department. They must elect courses in numerical analysis and scientific computing applications, and their thesis must be related to scientific computing in their discipline. The name of the student's degree is then formally appended with "... and Scientific Computing." Over 200 students have graduated from UM with this designation, representing 20 different departments across the University.

Leveraging the presence of the LaSC, the active research interests of faculty in Electrical Engineering and Computer Science and the support of the College of Engineering, Martin spearheaded a grant to the NSF in 1992 to obtain an nCUBE parallel computer. The NSF awarded a $2 million grant, and Martin became the founding director of the Center for Parallel Computing (CPC) that was set up to operate and maintain the nCUBE and provide access to UM users.

The NSF opened up a second competition for supercomputer centers in the late 1990s that would not just provide access to the largest supercomputers but also provide expert consultation and access to smaller systems (e.g. clusters) that were beginning to be used at the time. As a result of UM's track record with the LaSC and operating and maintaining the nCUBE system, UM was invited to join UCSD in a multi-university proposal, the National Partnership for Advanced Computational Infrastructure (NPACI). If awarded, the NPACI would fund a large computing platform at UCSD and smaller "mid-range" systems at the University of Texas at Austin and UM. Martin served as the principal investigator for the UM component of the UCSD proposal.

The NPACI proposal was funded for eight years and supported consultants who assisted users. The computing clusters totaled over 1,000 cores by the time the grant ended in 2005. In 2002, the CPC and the LaSC were merged into one unit, the Center for Advanced Computing (CAC), and Martin became the first director.

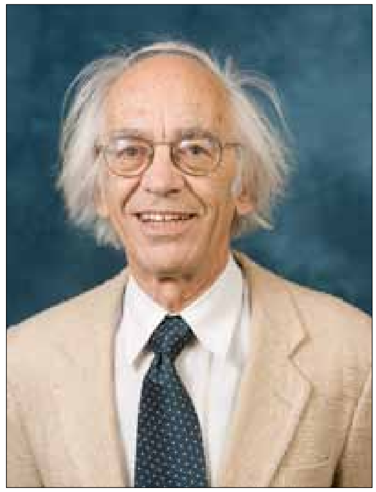
When Martin became chair of the Nuclear Engineering Department (in 1995 renamed Nuclear Engineering and Radiological Sciences) in 2004, he gave up his position as CAC director. Scientific computing at UM has continued to grow under new leadership and has evolved into the University-wide research computing unit, the Michigan Institute for Computational Discovery & Engineering (MICDE). The MICDE now serves as the focal point for the wide spectrum of research in computational science and engineering across the University.

New Faculty During the 1980s

As in previous decades, the 1980s also brought several new faculty members to the Department. Mary Brake joined the faculty in 1984 in the area of plasma physics and fusion. Brake represented the Department's first appointment of a female faculty member. By 2015, three women would hold faculty appointments. Unfortunately, Professor Brake would leave to begin a new career in secondary school teaching, later to become a professor at Eastern Michigan University.

David Wehe received his PhD from the Department in 1984 and joined the faculty in 1986 to focus on

Michael Atzmon



Ronald Fleming

Jim Duderstadt

development of instrumentation for gamma ray imaging for nuclear medicine applications as well as imaging systems for homeland security and industrial applications. He developed Compton scattering techniques that improve efficiency of conventional gamma ray cameras, and he also served as Michigan Memorial Phoenix Project director.

Edward Larsen joined the Department in 1986, after receiving his PhD in Mathematics from Rensselaer Polytechnic Institute, spending six years teaching mathematics at New York University and the University of Delaware, and nine years as a technical staff member at Los Alamos National Laboratory. (Larsen refers to his 31 years at UM as his third career!) His work has focused on development of advanced numeric and analytic mathematical algorithms for solving particle transport problems, including developing advanced methods for nuclear reactor applications, thermal radiation transport methods and charged particle transport methods for medical physics applications.

In 1987, Michael Atzmon joined the Department from California Institute of Technology with research interests in phase transformations far from equilibrium. His work focused particularly on the mechanical behavior of amorphous and nanocrystalline metal alloys as well as mechanochemistry and powder processing by mechanical attrition.

Ronald Fleming had been an early graduate student in the Department in the 1970s. He began his career in research at the National Bureau of Standards but returned to the Department in the 1990s to assume directorship of the Michigan Memorial Phoenix Project. In his later career he has been active in building joint instructional and research programs in China.

And a Loss... Well, Almost...

Because most faculty members were loath to become involved in University service activities, Jim Duderstadt found himself not only appointed to but also chairing numerous faculty committees. Like many younger faculty, he tended to approach each assignment with an activist agenda. For example, when he chaired the Curriculum Committee for the College of Engineering, he eliminated half of the courses in the College catalog on the grounds that they were rarely taught. When he chaired the Faculty Advisory Committee to the Provost (first Frank Rhodes and then Harold Shapiro), he led the charge to improve the research environment on campus. And when he served on the University's Budget Priorities Committee, he participated in an effort to downsize or eliminate a number of University departments and programs. In fact, Duderstadt became sufficiently visible as an activist faculty member that he was elected to the faculty governance leadership committee, the Senate Assembly Committee on University Affairs (SACUA).

One evening in the spring of 1981, while Duderstadt was minding his business as a budding radical in faculty governance, he received a phone call at home from Provost Bill Frye and was offered a Faustian bargain to become dean of the College of Engineering, an academic unit with over 300 faculty, 5,000 students and a budget of more than $100 million. At that time, Duderstadt's administrative experience was essentially nonexistent. He had never served as a department chair. He had never supervised anyone other than doctoral students. He also was only 37 years old and relatively unknown inside the College. However, Duderstadt also was brash and naive enough to view this as an opportunity to correct all the deficiencies he had been complaining about for years as a faculty member. After some deliberation and discussion, he decided this was something he had to do, and he accepted.

Assuming the role of dean started immediately. Duderstadt was introduced to the Engineering faculty the next day, and two weeks later he moved into the engineering dean's office. Throughout his first weeks, he met with each of the leaders of the College: department chairs, associate deans and key faculty. He was able to select his own team and surprised each of the associate deans by thanking them for their service and offering to help them return to the faculty. He then was able to talk several other young faculty members into joining the new administration, including Charles (Chuck) Vest, who would later become president of Massachusetts Institute of Technology, Dan Atkins, future dean of UM's new School of Information, and Scott Fogler, a leader in chemical engineering education.

Bill Frye had taken a chance by turning College leadership over to the young faculty. In a similar spirit, Duderstadt and his colleagues moved rapidly to restructure and rebuild the College. They first overhauled the salary program, then based primarily on seniority and rank, and instead moved to compensation based on merit. In the process, they shocked the College's assistant professors by doubling their salaries over a two-year period, stressing that the strong achievements of the assistant professors and the College's vulnerability to losing them to competition from other institutions demanded an aggressive salary program.

The North Campus Move...Finally Completed

As noted earlier, only two engineering programs (Nuclear Engineering and Aerospace Engineering) were located on the North Campus in 1980. Many faculty members were wasting hours every week commuting back and forth between campuses to conduct their research. The College was stalled, and it needed to complete the move before it sank in quality. The new deans' group decided that the College had to develop a creative plan to complete the move and then exert maximum pressure on the central administration to gain its support.

After a thorough review of the earlier plan to move the College into four new buildings, funded by state and private sources, Duderstadt realized it was clearly both impractical and unworkable in the current climate. The College's fundraising efforts in the 1970s had shown how difficult it was to raise gifts for buildings, with only a relatively modest building for the departments of Chemical Engineering and Materials and Metallurgical Engineering resulting (the Herbert H. Dow Building, then under construction and scheduled for completion in late 1982).

Duderstadt and the deans' group proposed a far more modest plan, based on the reassignment and renovation of several existing North Campus buildings:

- A small building housing the University's research administration would be reassigned and renovated to accommodate the Department of Industrial and Operations Engineering, and research administration would be moved to the West Engineering building.
- G. G. Brown Laboratory would be extensively renovated, adding a third floor for offices and renovating its high-bay research wing to accommodate the departments of Mechanical Engineering and Civil Engineering.
- The College would build a library and instructional center, with additional classrooms, in the excavated, but uncompleted basement of the Dow Building.
- An unused fraternity building adjacent to the North Campus, the Stearns building, would be used to house the Engineering placement offices.
- The Department of Naval Architecture and Marine Engineering would move into a small building adjacent to the old cyclotron laboratory.
- The College administration would move temporarily into the Chrysler Center, compressing the deans' offices and staff into about one-third the space it had been using in West Engineering.

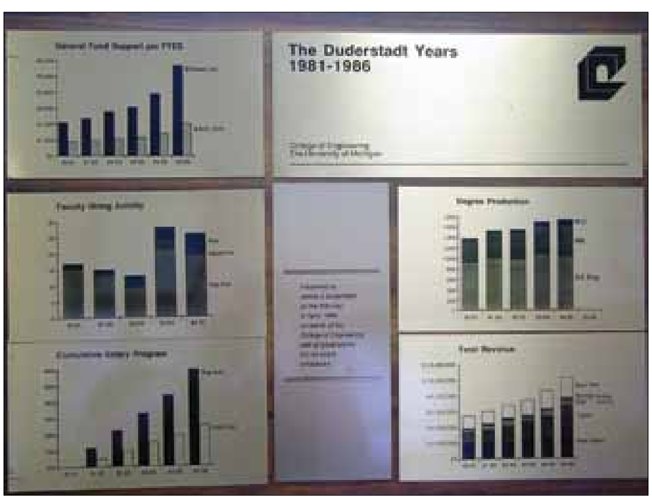
The new Dean of Engineering

Bombarding the administration with reports

Dean Chuck Vest

Dean Scott Fogler

Dean Dan Atkins



A plaque displaying the charts used to increase University funding of Engineering by 50%.

Persuading Governor Blanchard to fund Engineering Building I

Transforming the University of Michigan's North Campus

Herbert H. Dow Laboratory

Engineering Building I (EECS)

Campus Plan for the 1980s

Additions by the Duderstadt administration

The Engineering Campus in the 2000s

Carrying out these changes would result in the relocation of all of the College — with the exception of Electrical and Computer Engineering — to the North Campus within 18 months. Duderstadt convinced the University that the highest priority should be given to a state capital outlay request for $18 million for a new engineering building, referred to as "Engineering Building I," which would house the large Electrical Engineering and Computer Science department.

Although this plan required some modest expenditure by the University for the necessary renovations as well as the reassignment of space belonging to other units, it was regarded as a very pragmatic and efficient approach to completing the North Campus move in a relatively short time period. It would also release to the University all of the College's Central Campus space, with the exception of the naval architecture towing tank in the basement of West Engineering.

Normally such a complex plan would take many months of negotiation before a University decision was made. But two factors quickly put this plan on the fast track. First, on Christmas Eve 1982, an arsonist burned to the ground the University's Economics Building, adjacent to West Engineering. Ironically, Duderstadt had been taking an early Christmas morning jog over to the Central Campus when he noticed the smoke. He ran over and found Bob Holbrook, associate vice president for academic affairs and also a faculty member in economics, amid a group of fire fighters and police watching his office go up in flames. This event put great pressure on the University to find new quarters for the Economics Department; the College's proposed rapid departure from East and West Engineering could provide just such an opportunity.

Second, the College administration was fully prepared for the expected reaction from Provost Bill Frye — that he did not know where he could find the funds for these projects in the face of other budget pressures. College administrators immediately responded with an offer to lend the University $2 million from the College's discretionary funds to get the projects started. Frye quickly responded, "You've got a deal!" And Duderstadt and his team were off and running. (Some months later, Frye found $2 million in the provost's own accounts, so the College never actually had to transfer the funds for the loan.)

Within two months, the University was able to ignite the state capital outlay process for Engineering Building I (EBI), getting language into the state budget bill for $500,000 of planning funds to begin the project. There were still many hurdles to overcome in getting final legislative approval of what was to be a $30 million state-funded project. These included persuading Governor Blanchard that this building should be identified as one of his highest priorities. The North Campus move train was now rolling, and if it could be kept on schedule (and on the track), administrators anticipated that the entire College would finally complete its move by early 1986.

The last goal was achieved in June of 1983, when the EBI project received construction start authorization from the state legislature. Governor Blanchard flew in by helicopter to turn the first shovel of dirt at the construction-start ceremony, and bulldozers quickly converged on the site. The final piece of the North Campus move puzzle was now in place. The College needed only to finish construction of the massive EBI, now the Electrical Engineering and Computer Science building, to complete the move, and this would finally occur in spring 1996, after Duderstadt had moved on to the job of provost of the University.

Of course, once the move of all of the College's faculty, students and programs was complete, there still was more to do to improve the North Campus environment. Further investments were made to build an instructional center (library, computer center, instructional television) in the unfinished basement of the Dow Building. In addition, a connector laboratory was built between the Dow and G.G. Brown laboratories for bioengineering. A major addition was built to house the North Campus Commons (later named the Pierpont Commons). And the Space Physics Research Laboratory was doubled, and later tripled, in size before the end of the decade.

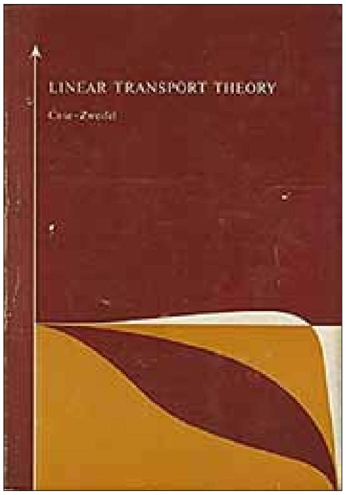
Books

Beyond the cutting-edge research in nuclear science and technology that enabled both the Department of Nuclear Engineering and the Michigan Memorial Phoenix Project to achieve global leadership, the

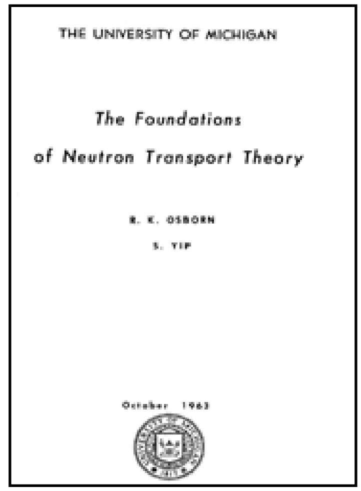
Department's faculty also were renowned teachers who wrote a number of leading textbooks. Throughout the 1980s, 1990s and 2000s, these textbooks defined the pedagogy and technologies of many of the authors' fields. Several of these books have become classic references and continue to be used today, decades after their initial publication. (A complete list of books by NERS faculty is provided in Appendix D.)

During the 1980s, the Nuclear Engineering department received a request from the electrical utility industry to go beyond producing textbooks and put its entire 10-course Bachelor of Science curriculum onto video. Many of the technical employees of nuclear plants across the nation had served in the nation's nuclear submarine program and wanted to further their technical knowledge by earning baccalaureate degrees in nuclear engineering. Fortunately, the College of Engineering had a high-quality television studio that was equipped for creating such instructional materials. The Department launched a massive effort, using its faculty, to put all 10 courses on high-quality videotape or computer disks for distribution to the utility industry. Each of the faculty participants in these productions was also asked to provide written workbooks for each course, containing all visual materials, problem sets and solutions. This multiyear effort was quite successful, and the materials were heavily used. Fortunately, the video-based courses were digitized at high quality and archived for continued use, with later access offered via the internet.

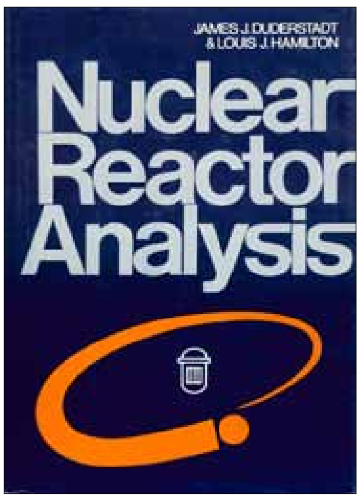
Today, such an effort would be referred to as a MOOC, a "massive open online course" (actually ten courses in this case). However, with concerns about the proliferation of nuclear technology to rogue states seeking to develop nuclear weapons technology, the Department decided not to circulate its nuclear engineering curriculum at the global level.



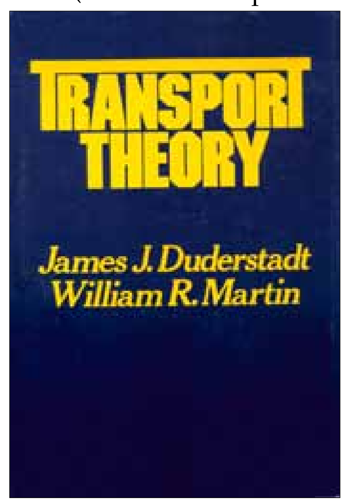
Linear Transport Theory (Case and Zweifel)



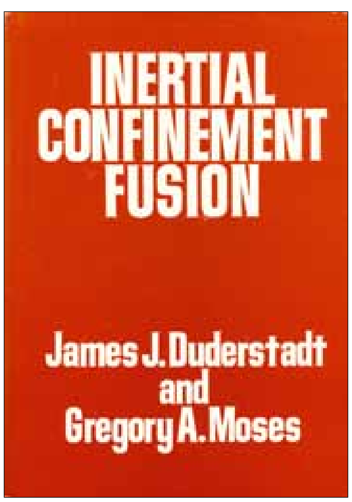
Foundations of Neutron Transport Theory (Osborn and Yip



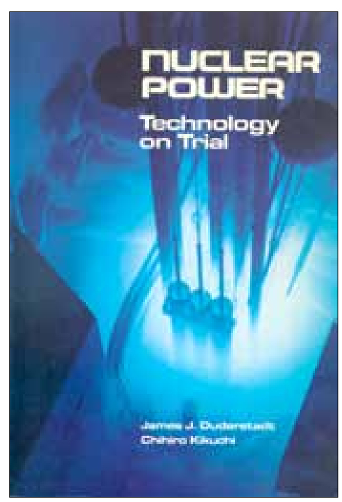
Nuclear Reactor Analysis (Duderstadt and Hamilton)



Transport Theory (Duderstadt and Martin)

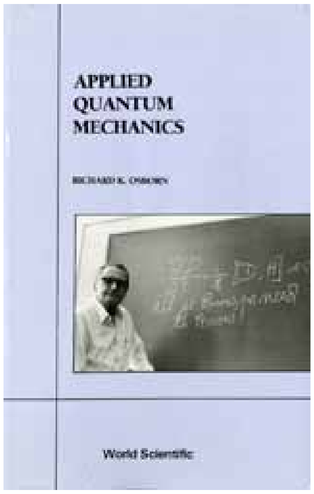


Inertial Confinement Fusion (Duderstadt and Moses)

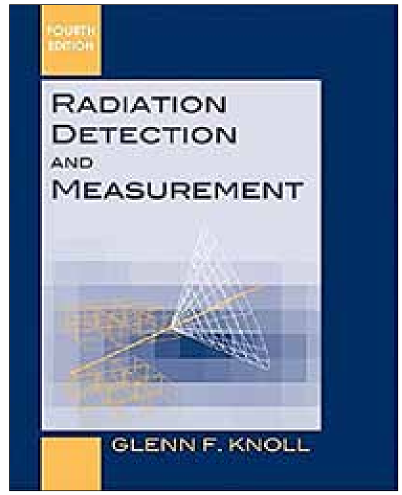


Technology on Trial (Duderstadt and Kikuchi)

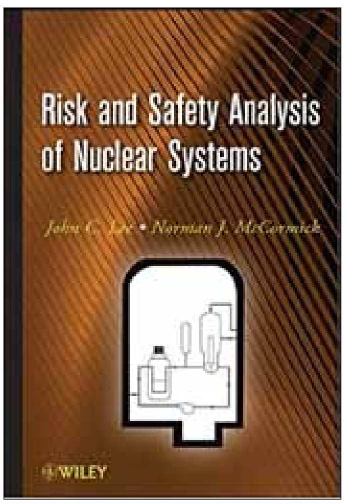
Books Authored by Faculty Members of the Department



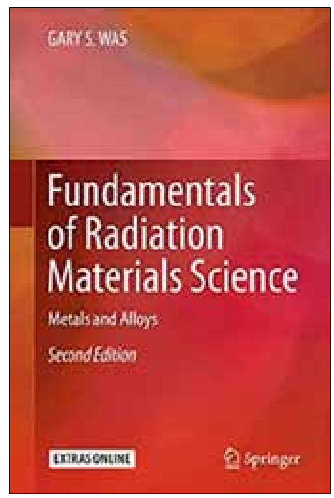
Applied Quantum Mechanics (Osborn)



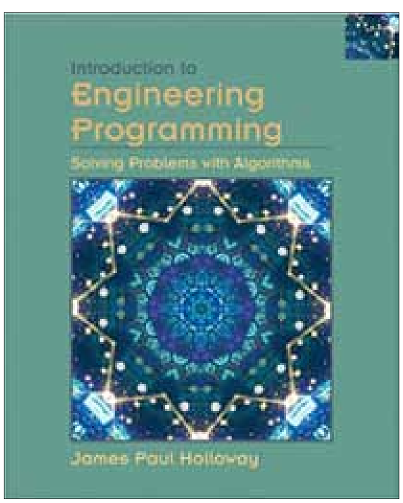
Radiation Detection (Glenn Knoll)



Nuclear Risk and Safety (Lee and McCormick)



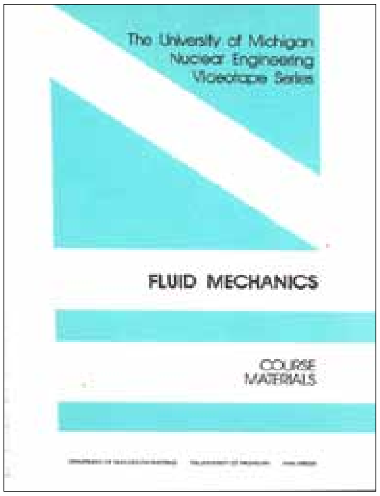
Radiation Materials Science (Was)



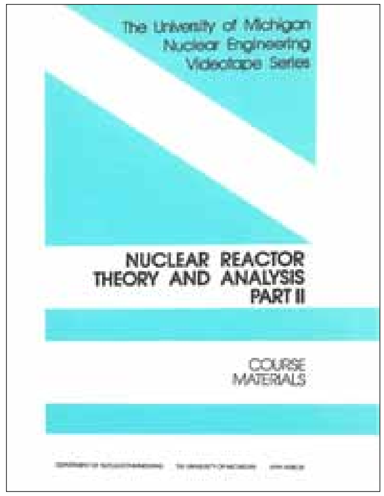
Engineering Programming (Holloway)

The "Nuclear Power and You" TV Series

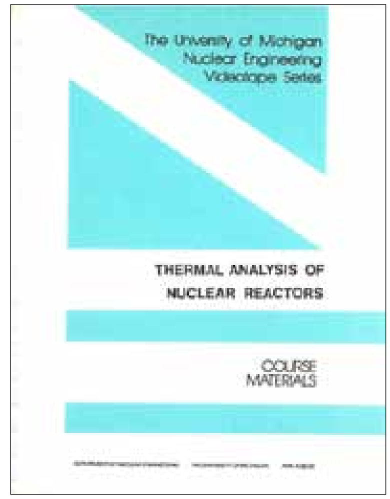
More Books by NERS Faculty...and a Five-part Documentary for Public Television



Fluid Mechanics workbook

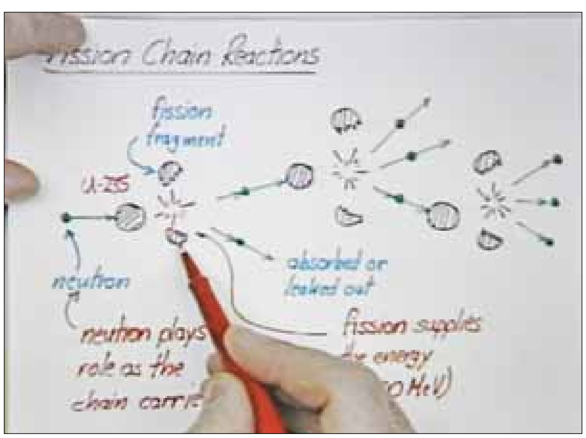


Reactor Theory workbook
for the NE "MOOC"

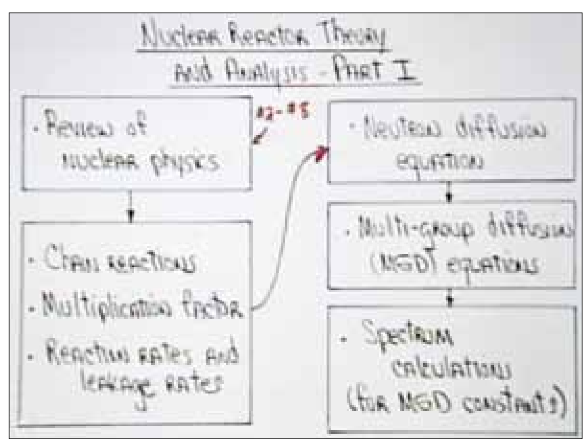


Thermal Analysis workbook


Bill Martin and Jim Duderstadt wideo



Video of explanation of fission

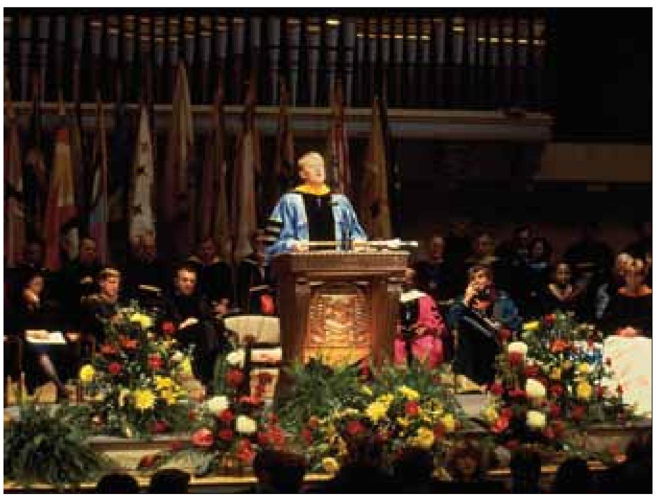


Video of organization of course

Video Curriculum Created for Nuclear Power Utilities (an early form of "MOOC")

1981 Dean of Engineering

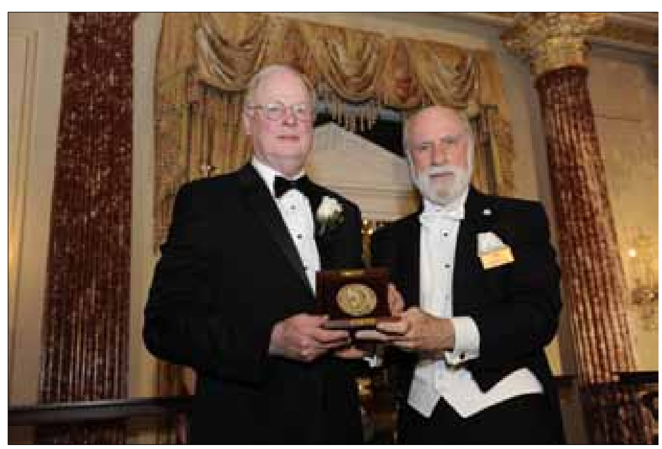
1986 Provost



1988 President of the University of Michigan

Chair, National Science Board
Chair, Nuclear Energy Research Advisory Committee

1991 National Medal of Technology



2015 Vannevar Bush Award

Duderstadt Sinks Even further into the Swamp of Academic Administration...

Chapter 6

1990s: Global Challenges

The 1990s were a time of transition for the Department, with a new chair (William Martin), a new Dean (Peter Banks), a new Provost (Charles Vest) and a new University President (James Duderstadt). Although there were many challenges — among them the declining level of support for nuclear power by the federal government — the Department benefited from an unusual situation: All of the leaders it depended on (chair, dean, provost and president) were engineering faculty members with a strong appreciation for nuclear science and engineering.

Department Activities During the 1990s

The 1990s were a difficult decade for nuclear engineering departments nationally, including UM Nuclear Engineering, and for nuclear energy more broadly. In 1993, nuclear energy research funding was marked for removal by the presidential administration. The U.S. Department of Energy's Nuclear Engineering Education Research (NEER) program was eliminated, and graduate students with fellowships and research assistantships suddenly lost their support in the middle of the 1993–1994 academic year. Together with the College of Engineering, the Department quickly had to provide alternate means of support so these students could continue their studies.

By 1998, U.S. Department of Energy funding for fission energy research had been eliminated entirely, taking away a significant source of research support from the Department. William Martin was serving as department chair at the time. (He would serve until 1994 and was appointed to a second term as chair a decade later, from 2004 to 2010.) Martin was the architect of a letter, signed by nearly 30 nuclear engineering department heads, to the presidential administration, urging a restoration of the budget for nuclear energy research and educational initiatives so vital to sustaining a key source of electricity for the nation.

William Martin
(Chair, 1990-1994)

Gary Was
(Chair, 1994-1999)

Not surprisingly, enrollment in nuclear engineering programs dropped sharply, and departments around the country began closing their doors. Resignations and retirements in the UM Nuclear Engineering department added challenges to an already discouraging environment. The situation required creativity and also brought with it opportunity.

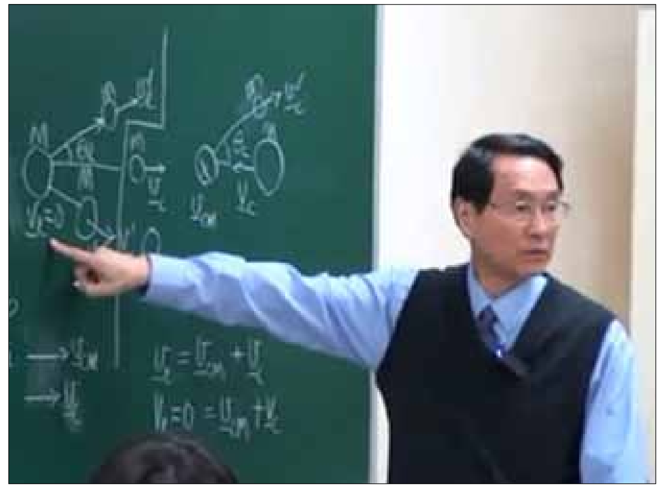
Upon his appointment as department chair following Martin, Gary Was continued to demonstrate the Department's perseverance. Was worked with the Nuclear Engineering Department Heads Organization (NEDHO) and enlisted congressional support to re-establish the NEER program and, subsequently, to initiate the Nuclear Energy Research Initiative (NERI). The NEER program was reinstated in 1998, during Was' term as chair of NEDHO. The NERI was subsequently created in 2000.

Under Was' leadership as department chair, faculty held what is believed to be the Department's first retreat, which led to a formalized strategic planning process and the first strategic plan. The Department also established its first External Advisory Board, comprised of industry, university and government leaders, a job placement program for graduates and a four-year financial support program for undergraduates.

The Department broadened its reach to include radioactive waste materials and medical applications of radiation and, in 1995, its name was changed to Nuclear Engineering and Radiological Sciences (NERS) to reflect this evolution. The undergraduate program was expanded to include a second track in Radiological Sciences, in addition to Nuclear Engineering.

In 1998, the Department, Westinghouse and China National Nuclear Corporation (CNNC) signed a memorandum for a long-term collaboration to train master's degree students from CNNC in reactor safety at UM NERS, with Westinghouse providing fellowships. The program successfully lasted for seven years, from 1999 to 2006, and 13 engineers from CNNC completed their M.S. program in the NERS department with two months of practicum at Westinghouse headquarters in Pittsburgh.

Through this program, the NERS department established a close relationship with CNNC leaders and their institutions throughout China. Several of the students are now working in important research



John Lee
(Chair, & MMPP Director) 1999-2004)

and management positions in CNNC institutions and new nuclear power plant sites. The education program played an important role in the successful sale of four Westinghouse AP1000 nuclear reactors to China in 2007 in a $5.5 billion deal. It was unfortunate that Westinghouse decided to stop funding the program in 2007, since China was to make a major commitment to building Generation III nuclear plants, and this would require training large numbers of nuclear engineers — precisely the goal of the NERS program. The Department also explored similar training programs with both Japan and France.

All told, the changes kept the Department going, and arguably made it stronger, by the end of the decade. While at one point in the 1990s, the number of faculty had dropped to nine, the Department had been able to secure approval from the College dean for several new positions, bringing the number of faculty to 16 by 1999. At the same time, the retirement rate of first-generation engineers from the nuclear industry exceeded the number of graduates in the field. With demand rising, graduates secured nuclear engineering jobs, and enrollment began to increase. This had been predicted in an American Society for Engineering Education report authored by Martin and Was that was the first manpower assessment in the nuclear industry. The report predicted that in the year 2000, the graduation rate would dip below the hiring rate. It did, and most all nuclear engineering programs in the country saw their first uptick in enrollment in years.

Professor John Lee took over as Department chairman in 1999 while serving concurrently as director of the Michigan Memorial Phoenix Project. In his first year as chair, Lee oversaw the organization of a two-day symposium to be held in the fall of 1999 to celebrate the 50th anniversary of the Phoenix Project and its role as a truly unique World War II memorial. Professor Kerr served as honorary chair with professors King and Fleming serving as co-chairs of the momentous event.

New Faculty during the 1990s

James Holloway (1990): neutron and photon transport, nuclear reactor physics, plasma theory computational physics

Kimberlee Kearfott (1993): personal dosimetry, radiation detection, radiation protection, health physics

Zhong He (1994): radiation imaging detectors, PET nuclear imaging, gamma-ray astrophysics

Don Umstader (1995): laser-plasma interactions and accelerators

Alex Bielajew (1997): Monte Carlo code development, electron transport theory, radiation standards

Lumin Wang (1997): nuclear fuel cycles, particle beam processing, microstructure materials analysis

Rodney Ewing (1997): radiation protection, radioactive waste disposal

James Holloway joined the department as an assistant professor in 1990. His work has focused on computational and mathematical modeling of neutral particle transport, plasma kinetics and hydrodynamics, and related research on inverse problems and plasma tomography. Along with his students, Holloway developed the first Riemann solvers for time-dependent neutral particle transport, which included the first successful solutions of low-order nonlinear maximum entropy closures for transport equations. He and his students also developed methods for discretizing infinite dimensional Hamiltonian systems such as the Vlasov equation into finite dimensional systems that preserved symplectic structure. They explored spectral discretization in several contexts, including in functional expansion tallies for Monte Carlo methods. Holloway served as co-principal investigator on UM's Center for Radiative Shock Hydrodynamics (CRASH) and led the Center's uncertainty quantification

James Holloway

program. As part of that effort, he and the team pushed several statistical ideas in model calibration and model emulation into large-scale simulations calibrated with limited experimental data. He served as editor-in-chief of the journal *Transport Theory and Statistical Physics*.

Holloway also conducted research in engineering education, including studying student identity and gender in the engineering classroom. He taught everything from large first-year classes to specialized graduate-level courses and much in between, including ENGR 260, Engineering Across Cultures, not only in Ann Arbor but also in Kumasi, Ghana, and Chiang Mai, Thailand. In 2007, he was named an Arthur F. Thurnau Professor in recognition of outstanding contributions to undergraduate education. Later that year, he became associate dean for undergraduate education for the College of Engineering. In 2013, he joined the provost's office as Vice Provost for Global and Engaged Education and, in 2016, was named Vice Provost for Global Engagement and Interdisciplinary Academic Affairs.

With strong interests in radiation dosimetry, environmental radionuclide modeling and measurement, radioactive waste management and radiation health physics, Kimberlee Kearfott serves as NERS professor with additional appointments in Biomedical Engineering and Radiology. She directs several important laboratories, including the Radiological Health Engineering Laboratory for the development and testing of new systems for application to radiological health problems, a major radiation dosimetry measurement laboratory, and a laboratory


Kimberlee Kearfott


Zhong He


Alex Bielajew

capable of measuring natural sources of radiation in the environment, such as radon from U-238 decay and other naturally occurring radionuclides as well as those produced by nuclear activities. Of particular note is Kearfott's work on measurement of radiation doses to individuals due to internally deposited radionuclides whether as patients or through natural exposure.

Kearfott also has been extremely active as a member of the University's faculty government, serving for several years as a member of the Senate Advisory Committee on University Affairs and chairing the University Faculty Senate from 2012 to 2013.

Zhong He joined the Department first as a postdoctoral scholar and then as a research scientist. He was appointed to the instructional faculty in 1998 to teach and conduct research in the field of detector science. His particular interests have been in position-sensitive room-temperature semiconductor radiation imaging detectors, low-noise charge sensitive application specific integrated circuitries, gamma-ray image reconstruction, gas and scintillation radiation detectors, PET nuclear medicine imagine, and experimental gamma-ray astrophysics. He invented the 3D-readout technique for semiconductor detectors that forms the foundation of all high-definition 3D technology, enabling high energy resolution and the ability to perform gamma-ray imaging with a single cadmium zinc telluride (CdZnTe) crystal. He has won several awards from the Department for his activities.

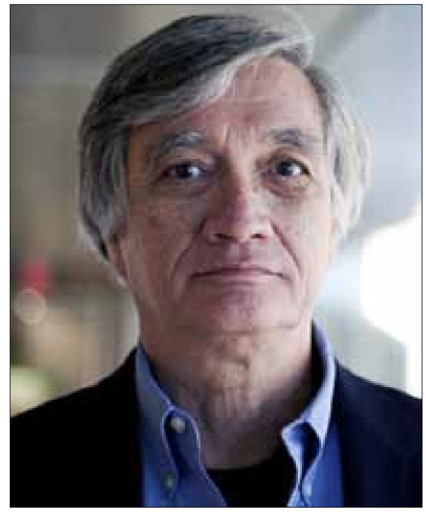
Alex Bielajew also joined the Department in the mid-1990s, first as a visiting professor from Canada, then joining the permanent faculty in 1997. His research is in the area of Monte Carlo code development, studying variance reduction in the method, then developing Monte Carlo codes for the calculation of electron transport, electron elastic multiple scattering and radiation standards. He has also conducted research on the theory of ionization chambers and theories for modeling radiation dose deposition for medical physics purposes. He is a Fellow of the United Kingdom's Institute of Physics.

Lu-min Wang's specialty is nuclear engineering materials and transmission electron microscopy (TEM) characterization of materials at the nanoscale, especially materials irradiated with ion beams or other energetic particles. He has a broad international collaboration with researchers in the fields of material science, nuclear engineering, geology/mineralogy, environmental science and engineering, chemistry and chemical engineering. Of particular importance has been the application of his research to nuclear fuel cycles, including the development of new types of reactor fuels and waste management. He has also developed techniques for using TEM for the study of microstructure evolution of solids under irradiation of energetic particles and particle beam modification of materials for engineering applications and processing of nanostructures.

Rodney Ewing arrived as a full professor to UM NERS in the fall semester of 1997. Ewing's goal was to create courses and a research program focused on the back end of the nuclear fuel cycle. He created a graduate-level course, Nuclear Waste Management, which he taught to large enrollments. With Lu-min

Lu-min Wang

Don Umstadter



Rodney Ewing

Wang, he also created a strong research program in particle-solid interactions in ceramics that included nuclear waste forms and nuclear fuels. He was named the William Kerr Collegiate Professor in 2002, and in 2004 moved to Geological Sciences as his home department but retained appointments in NERS and Materials Science & Engineering. He has since moved to Stanford University, where he is the Frank Stanton Professor of Nuclear Security in the Center for International Security and Cooperation.

The Nuclear Energy Research Advisory Committee (NERAC)

Although no longer an active member of the Department of Nuclear Engineering and Radiological Science, Jim Duderstadt continued to play a major role in nuclear power activities at the national level. During the 1990s he was appointed as the first chairman of a new Department of Energy organization, the Nuclear Energy Research Advisory Committee (NERAC).

Growing Concerns

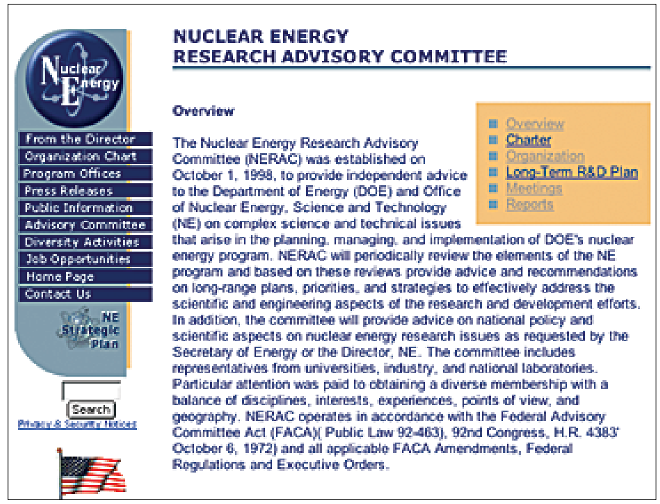
The nation's research programs in peaceful uses of atomic energy decayed rather significantly in the 1990s. Key programs such as the Advanced Light Water Reactor program and the Integral Fast Breeder Reactor program were completed or phased out. In fact, by 1997, Department of Energy funding of advanced reactor technology had dropped essentially to zero. The President's Council of Advisors on Science and Technology (PCAST) warned that the future of this technology in the United States was in considerable doubt.

"Fission's future expandability is in doubt in the United States and many other regions of the world because of concerns about high costs, reactor-accident risks, radioactive-waste management, and potential links to the spread of nuclear weapons. We believe that the potential benefits of an expanded contribution from fission in helping address the carbon dioxide challenge warrant the modest research initiative proposed here (the Nuclear Energy Research Initiative), in order to find out whether and how improved technology could alleviate the concerns that cloud this energy option's future. To write off fission now as some have suggested, instead of trying to fix it where it is impaired, would be imprudent in energy terms and would risk losing much U.S. influence over the safety and proliferation resistance of nuclear energy in other countries. Fission belongs in the R&D portfolio."

Of related concern was the erosion in academic programs and facilities required to produce the human resources for the nation's nuclear industry and nuclear defense programs. Over the course of the decade, the number of nuclear engineering programs in the United States declined by half (from 80 to 40), the number of university research and training reactors by two-thirds (from 76 to 28), and enrollments by almost 60% (from 3,440 to 1,520). As noted in a 1990s planning study:

"Nuclear engineering programs in the United States

U.S. Department of Energy headquarters



NERAC Charge

are disappearing. Without concerted action by Department of Energy, supported by Office of Management and Budget and the Congress, most of the existing nuclear engineering programs will soon evaporate or be absorbed and diffused in other engineering disciplines."

NERAC Mission

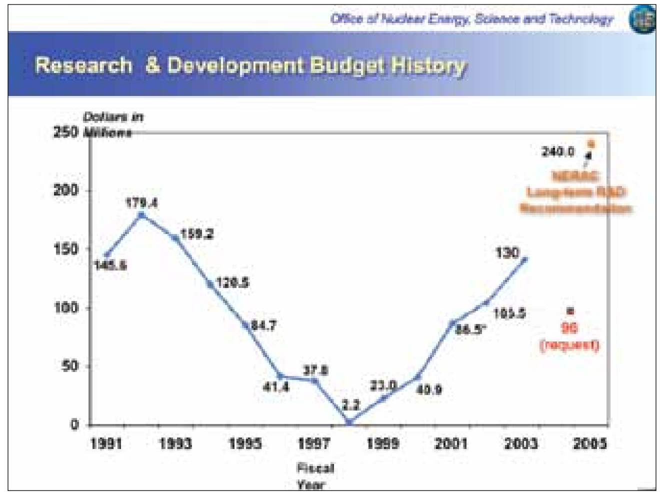
NERAC was established in 1998 to provide independent advice to the U.S. Department of Energy (DOE) on complex science and technical issues that arise in the planning, managing and implementation of the DOE's nuclear energy program. NERAC assisted the DOE by reviewing the research and development (R&D) activities of the Office of Nuclear Energy, Science and Technology and providing advice and recommendations on long-range plans, priorities and strategies to effectively address the scientific and engineering aspects of these efforts. In addition, the committee provides advice on national policy and scientific aspects of nuclear energy research issues as requested by the Secretary of Energy or the Director of the Office of Nuclear Energy. In particular, the Secretary of Energy requested that NERAC assist DOE in developing a long-term nuclear energy R&D plan, identifying priorities and possible programs along with an assessment of funding and infrastructure needs. The Committee was also tasked with evaluating the DOE's physical infrastructure for nuclear energy research (e.g. research reactors, hot cells, and accelerators) in light of the needs suggested by the long-range nuclear energy R&D plan. In addition, NERAC was asked to assess the current crisis in university nuclear engineering programs and campus-based research facilities in light of the nation's growing human resources needs.

Longer Range Planning Activities

Although the planning efforts begun in the 1990s were intended to be ongoing and evolutionary, they do provide a strong sense of priorities for the DOE in the years ahead. The committee had a diverse membership with a balance of disciplines, interests, experiences, points of view and geography and spanned academia, industry and national laboratory communities.

Largely as a consequence of this planning effort, the nation began to expand its investment in nuclear research to the point where it reached over $240 million a year during Duderstadt's tenure as chair of NERAC. But there was one more project launched by NERAC that deserves specific mention because of its importance to the Micihigan Memorial Phoenix Project and the Department of Nuclear Engineering and Radiological Science. Because of the growing concern about sustaining the presence of nuclear reactor facilities on university campuses for both teaching and research, the NERAC created a competitive grants program to sustain these important resources.

Here Duderstadt believed that the Ford Nuclear Reactor was just such a resource and would be highly competitive to receive funding from this NERAC program. Unfortunately, as will be described in the next chapter, the University of Michigan did not receive one of these grants. But even more serious was a political decision in the early 2000s by a new UM president to decommission the University's reactor, despite the strong concerns of both the nuclear industry and the Secretary of Energy that this action would damage the national interest.



Decline and growth in DOE fission energy research

Chapter 7

The 2000s: Into the New Millennium

With the new millennium came both new achievements and new challenges. As concerns about the impact of carbon emissions on global climate grew, nuclear power became highly competitive with fossil fuel plants, and there was a "renaissance" in new plant orders during the early years of the decade, with over 40 applications for construction and operating licenses from the Nuclear Regulatory Commission. The Bush administration set new priorities for the development of advanced Generation IV nuclear reactors, and the U.S. Department of Energy once again began to fund nuclear science and engineering on university campuses.

Yet, in sharp contrast to the national optimism, a new president at the University of Michigan was persuaded by ill-considered safety questions to order the decommissioning of the Ford Nuclear Reactor, despite the deep concern about such action by the U.S. Secretary of Energy.

Despite the optimism early in the early 2000s of the 2000s, the emergence of gas shale fracturing began to provide low-cost natural gas power with only half the carbon emissions of coal-fired plants. This competition from cheaper gas-fired power plants, coupled with deregulation of the electric power industry in most states, collapsed the brief optimism about further nuclear plant construction. The nuclear renaissance came to an end by the end of the decade, with only four AP1000 plants under construction in the southern states.

New Leadership

Carrying the efforts of his predecessors forward, Department Chair John Lee, too, continued working with the U.S. Congress to restore and increase federal funding for both nuclear engineering departments and university research reactors. A testament to the tireless work of faculty and Department leaders throughout the turbulent 1990s, U.S. News & World Report ranked the NERS graduate program #1 in the country in 2006. Also that year, the Michigan Memorial Phoenix Project was recognized by the American Nuclear Society (ANS) as "a unique and pioneering atomic research program, as a permanent memorial to the University's soldiers who fought and died in World War II, and as a symbol of the University of Michigan's commitment to the peaceful and socially responsible use of science and technology."

Educational Advancement

The early part of the 2000s brought several new education initiatives and courses. In 2001, the Department began adding communications to seven undergraduate courses as part of the College of Engineering Curriculum 2020. The following year, the NERS department introduced a new course, NERS 250: Fundamentals of Nuclear Engineering, to provide second-year students with an in-depth introduction to the discipline.

Adding more flexibility to the curriculum, NERS 190: Special Topics in Nuclear Engineering and Radiological Sciences, was created so that courses could be taught on an experimental basis to first- and second-year engineering students. Jim Duderstadt, by 2003 President Emeritus, taught the first section of newly formed course, Technology Challenges for the 21st Century.

At the graduate level, an advanced course in radioactive waste forms was introduced during the 2000–2001 academic year, signifying continued Departmental efforts to strengthen the instructional program in this continually developing field.

Growth of the NERS Department

By mid-decade, many of the struggles the Department had faced in the 1990s had been resolved. Between 2004 and 2008, the Department added several faculty members, making it one of the largest in the country by faculty size. The College of Engineering authorized the new hires in part due to the anticipated growth in demand for well-trained nuclear engineers and the improving prospects for nuclear power.

A new energy bill, the Energy Policy Act of 2005, which provided tax credits for power produced by advanced nuclear power plants, and a more favorable national sentiment toward nuclear power more generally as a source of carbon-free energy, pointed to a so-called "nuclear renaissance," although this was soon to be challenged by the economic competitiveness of gas shale fracturing technology.

William Martin assumed a second term as chair in 2004 and described it as "night and day" compared with the obstacles the Department had faced a decade prior. The College of Engineering dean, David Munson, supported nuclear energy as an important source of electricity and was supportive of the Department's efforts to hire new faculty and expand programs.

The efforts did not go unnoticed. In 2005, the Department received six-year accreditation from ABET (formerly the Accreditation Board for Engineering and Technology) and, the following year, took the top spot as the nation's #1 graduate program in nuclear engineering as determined by U.S. News & World Report.

Students, too, were motivated, intellectually curious and ambitious. The ANS recognized the exceptional achievements of the UM student chapter with its 2005 Samuel Glasstone Award, given to an outstanding student section in the United States for notable achievements in public service and the advancement of nuclear engineering. The following year, the UM student chapter received the UM College of Engineering's Elaine Harden Award for best student professional society.

Also in 2005, several NERS undergraduates joined the UM Engineering Study Abroad program at Shanghai Jiao Tong University in China. Professors Lee and Martin visited SJTU to teach a course on Reactor Safety Analysis.

By the time the Department reached its 50th anniversary in 2008, it had plenty to celebrate. It again had earned the top spot in U.S. News & World Report's rankings after vying for first place with Massachusetts Institute of Technology in 2007. And it was celebrating substantial increases in undergraduate and graduate enrollment. In just one year, the graduate program had gone from 21 incoming students in 2007 to 38 in 2008.

Faculty hires in the 2000s included:

John Foster (2006): plasma science
Karl Krushelnick (2006): high-intensity laser plasma interactions
Michael Hartman (2007-2012): established the Neutron Science Laboratory
Sara Pozzi (2007): radiation detection and nuclear nonproliferation
Thomas Downar (2008): computer code development and fission reactor applications
Alexander Thomas (2008): experimental and theoretical plasma physics

John Foster received his PhD from the UM Applied Physics program and after postdoctoral work at NASA joined the NERS faculty in 2006. His research focus is on understanding and applying plasma science to real world problems, with particular activities in low-temperature plasmas, plasma physics for space applications, plasma diagnostics and modeling of plasma phenomena and environmental plasma processes. His strong interest in space propulsion has stimulated a particular focus on space-related plasma projects. Beyond space propulsion, his work is also concerned with improving the environment through the use of plasma-based remediation technologies. Foster's laboratory pays particular attention to applications that protect the environment and improve the quality of life in developing countries. His lab will pursue research opportunities in processing plasma applications, energy conversion and energy production.

Karl Krushelnick also joined the NERS department in 2006 and became the director of the Center for Ultrafast Optical Science (CUOS) in 2011. His research involves high-intensity laser plasma interactions and


John Foster


Karl Krushelnick


Alex Thomas

laser-driven particle acceleration for radiation generation, medical applications, homeland security, fusion and laboratory astrophysics. Facilities at UM include the 300 TW Hercules laser system, the 25 TW T-cubed laser and the high repetition rate Lambda-cubed laser. Hercules has held the record for highest peak laser intensity since 2008, and an upgrade for Hercules to a power approaching 1 PW (10^15 watts) was later funded by the National Science Foundation in 2017.

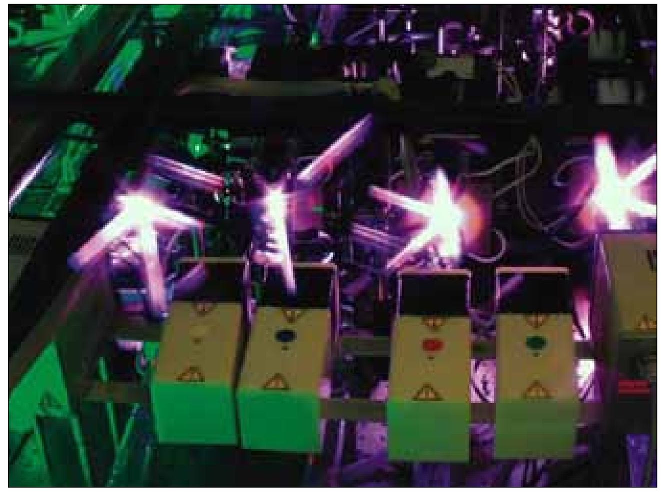
The Department already has been contributing to fusion sciences in a number of areas. In particular, inertial confinement fusion-related research has emerged as a special strength, and efforts likely will continue to focus on further extending this area in the future. Maintaining the department's leadership in inertial fusion-related facilities, such as the MAIZE Z-pinch and HERCULES and T-cubed laser systems through upgrades — and acquiring and developing new facilities, such as the recently-acquired BLUE-Ursa-Minor LTD and a high-energy, long-pulse laser system will be crucial. Specific research areas for development include understanding fundamental instabilities under inertial fusion-related conditions, alternative ignition schemes leveraging pulsed-power or short-pulse laser capabilities, diagnostic development for fusion experiments and developing kinetic plasma models for fusion that leverage the substantial transport theory expertise in the Department as a whole.

Alex Thomas conducts research in experimental and theoretical plasma physics. His research is focused on the physics and applications of high-power laser interactions with plasma. When heated by lasers, highly non-equilibrium states of matter arise, where complex behavior such as collective wave-particle interactions is prevalent and only full kinetic descriptions of the particle distribution are valid. Light and plasma couple together strongly, leading to instabilities and nonlinear wave formation. At the highest intensities, quantum electrodynamic effects become important in determining the plasma dynamics. Applications of intense laser-driven plasma include advanced, miniature particle accelerators, next-generation photon sources and inertial fusion energy. Thomas is part of the CUOS High Field Science group, using the HERCULES and Lambda-cubed very-high-power laser systems for investigating the physics of relativistic plasma.

Sara Pozzi joined the faculty in 2007 and that same year founded and has continued to lead the Detection for Nuclear Nonproliferation Group (DNNG), a research group within NERS. The DNNG works in the areas of radiation detection, homeland security and nonproliferation of nuclear weapons. The laboratory is known internationally for development of the Monte Carlo code MCNPX-PoliMi (Politecnico di Milano), a complex computer code that predicts the response of radiation detectors to nuclear materials. This code has been widely adopted in the United States and other countries around the world and was used to develop new technologies in homeland security, radiation detection, medical physics and basic physics.

The DNNG has pioneered the use of new scintillators as neutron detectors in instruments that can detect,

The Hercules laser compression chamber



Ultrafast lasers becoming more intense

locate and characterize special nuclear materials such as uranium and plutonium that can be used in a nuclear weapon and cause great destruction. These instruments were successfully tested in experiments performed in laboratories around the world. The technology that Pozzi and her team have developed is extremely relevant to scientists at the International Atomic Energy Agency in Vienna, Austria, who are interested in the next generation of instruments used by nuclear facility inspectors around the world.

Tom Downar joined the faculty in 2008 and brought to the Department expertise in computer code development and fission reactor applications that complemented existing NERS expertise in neutron transport methods. Downar brought with him from University of California, Berkeley, and Purdue University a team of staff and students who had developed the U.S. Nuclear Regulatory Commission (NRC) code, PARCS, which had become the core neutronics simulator to certify the safety performance of all U.S. and several international reactors. Since 2008, the NRC has continued for provide several million dollars of research funding for Downar and his group to continue developing PARCS, not only for licensing the current fleet of light water reactors but also for the wide range of advanced concepts being considered for next-generation reactors.

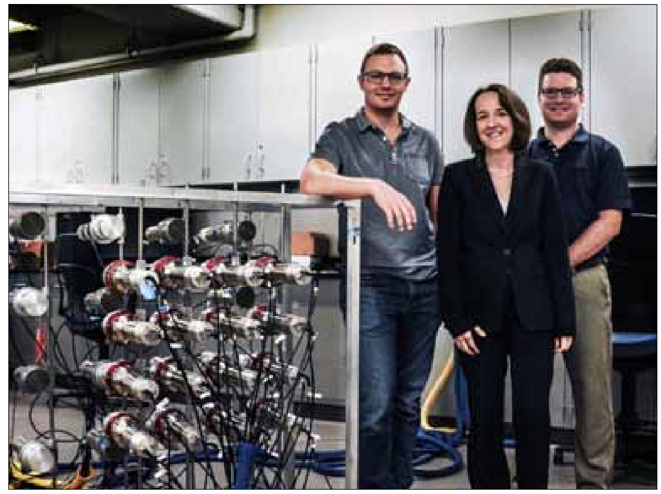
A Tragic Decision

The Ford Nuclear Reactor, one of the first three campus-based research reactors in the nation, remained highly utilized for both scientific research (e.g. neutron scattering), medical applications (e.g. producing key isotopes for medical therapies), and technology training purposes. Its 24-hour operation enabled experiments and other applications unavailable at most other research and power reactor facilities. Since the reactor required continual staffing, maintenance and upgrading, in 2000 Jim Duderstadt — then chair of the Department of Energy's Nuclear Energy Research Advisory Committee — shepherded a competitive grants program to provide sustained support for such facilities, with the hope that the Ford Nuclear Reactor would win an award.

The winning proposals went to a consortia of campus nuclear reactors, but UM had chosen to go it alone in order to comply with specific requests from the University administration to obtain sufficient funding to support reactor operation and upgrade. Joining a consortium would have meant fewer available funds. Unfortunately, UM finished out of the running. This was only a sign of something far more serious that was to happen: the decision in 2002 of a new University president, Mary Sue Coleman, to shut down the Ford Nuclear Reactor and have it decommissioned.

While the University's Office of Research was often under pressure to reallocate funding among projects, the real pressure came from a member of the Board of Regents, who developed the (mistaken) idea that the reactor presented a threat to the student population of the North Campus. The reactor had operated successfully for almost 40 years without incident, and

Sara Pozzi



Sara Pozzi and the DNNG technologies

its regulation by the Nuclear Regulatory Commission provided strong evidence of its strict adherence to safety regulations. Still, the new president proceeded to order decommissioning of the facility. When the U.S. Secretary of Energy became aware of the decision, he contacted President Coleman personally to implore her to reverse her decision because of the importance of the Ford reactor as a national resource. The Secretary assured President Coleman that the U.S. Department of Energy would provide sufficient funding for its continued operation.

Unfortunately, Coleman was determined to move ahead with decommissioning, despite the impact this would have on both the Department and the nation, and the University announced its decision in August 2002. By the end of July 2003, the reactor had been shut down and the decommissioning process had begun.

Department Chair John Lee and others in the NERS department went to great lengths to reduce the impact of the reactor shutdown on both education and research. In an arrangement with Dow Chemical Company, senior students in NERS 445, Nuclear Reactor Laboratory, and NERS 425, Applications of Radiation, were able to perform key experiments at the company's TRIGA reactor in Midland, Michigan. With the support of two NERS alumni, Ward Rigot and Siaka Yusuf, Ron Fleming was also able to take his lab classes to Midland for important experiments. Lee also organized a three-day Symposium on Energy and Environment: The Role of Nuclear Power to address environmental challenges, proliferation risks, and development of nuclear energy.

The decommissioning process would last ten years and cost over $20 million, far beyond the cost of continuing to operate the reactor. It also had a serious impact on both the activities and the morale of the Department that had depended on the reactor for much of its experimental research, including on neutron scattering, isotope production and radiation measurements. It became increasingly clear that the Department's reputation and impact would remain at risk until it could build new experimental capacity — a task that would not be fully achieved until 2017, some 15 years after the decision to decommission the Phoenix Memorial Laboratory's primary experimental facility.

Shortly after the decommissioning process had begun, the Department secured funding, including through the U.S. Department of Energy and the UM College of Engineering, to purchase two neutron generators. These would provide students and University researchers with accelerator-based neutron sources for their work. In true Phoenix spirit, the Neutron Science Laboratory officially opened in 2007 and would support many investigations related to radiation safety and homeland security in the coming years.

The Consortium for the Advanced Simulation of Light Water Reactors (CASL): An Energy Innovation Hub

In 2010, William Martin began the Michigan Project to support the Consortium for Advanced Simulation of Light water reactors (CASL), a multi-institution

Tom Downar

partnership including the University of Michigan, supported by the U.S. Department of Energy (DOE). Martin served as principal investigator for the UM CASL effort as well as the lead for CASL's Radiation Transport Focus Area, responsible for development and implementation of radiation transport codes across the CASL partnership. This research organization, funded at $25 million per year, was the first of the DOE's Energy Innovation Hubs. Given its success, in 2015 CASL was extended for another five years, to 2020.

The arrival of Tom Downar strengthened the team. Downar's interests were in the development of computational methods for the solution of problems in reactor physics, reactor thermal analysis and their application to the design and analysis of various reactor technologies — just the background to strengthen the UM CASL team.

CASL represented a new approach to research for the DOE. Accelerated and translational R&D, from fundamental discovery to commercialized technology, has nevertheless proven challenging for nuclear energy; innovations are difficult in an enterprise that that is inherently conservative and regulatory-driven.

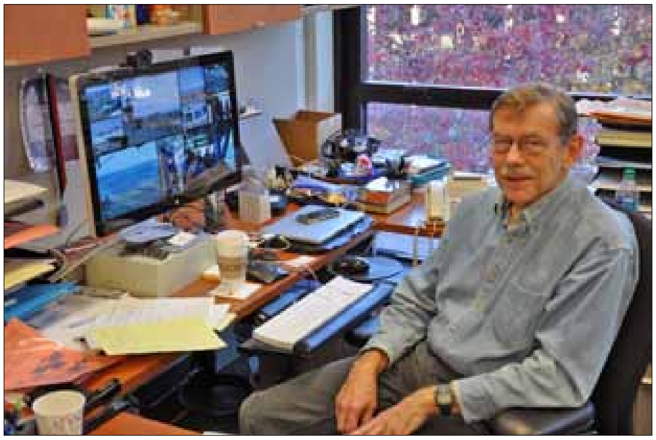
Translational research, a high-return proposition for nuclear energy, is exactly what Energy Innovation Hubs, established by the DOE in 2009, strive to enable and accelerate. Hubs bring together teams of top scientists and engineers from academia, industry and government to collaborate and overcome critical barriers to achieving national climate and energy goals that have proven resistant to solution via the normal R&D enterprise. Hubs focus on a single topic, with the objective of rapidly bridging the gaps among basic research, engineering development and commercialization through a close partnership with industry. To achieve this goal, hubs necessarily consist of large, highly integrated and collaborative creative teams working to solve priority technology challenges.

The UM NERS department has played a major leadership role in CASL's focus on innovating commercial nuclear power generation, specifically the modeling and simulation (M&S) of nuclear reactors. CASL not only strives to bring innovation to the nuclear energy enterprise but also to help retain and strengthen U.S. leadership in two DOE mission areas: high performance computing-enabled M&S and nuclear energy.

CASL's mission is to recapture the benefits of leadership in M&S for nuclear technology by providing coupled, high-fidelity, usable capabilities needed to address light water reactor (LWR) operational and safety performance-defining phenomena. Its unique partnership of government, academia and industry possesses unparalleled collective institutional knowledge, nuclear science and engineering talent, computational science leadership, and LWR design and regulatory accomplishments. CASL has several key elements: clear deliverables and products that solve industry issues and are driven by a well-defined yet dynamic plan for executing on deliverables; a strategy of delivering prototype products early and often; and defined customers and users.

In its first several years, CASL has already been remarkably successful in developing new simulation tools such as VERA, a Virtual Environment for Reactor Analysis, based on state-of-the-art petascale supercomputers such as Titan and Summit at Oak Ridge National Laboratory. These simulations have achieved dramatic advances in the ability to enhance the economic performance and safety of existing nuclear power plants and will serve as important design tools for future generations of nuclear systems.

After the formation of CASL in 2010, Tom Downar and his group led the development of the next-generation neutronics code MPACT (Michigan PArallel Characteristics Transport), which has been the

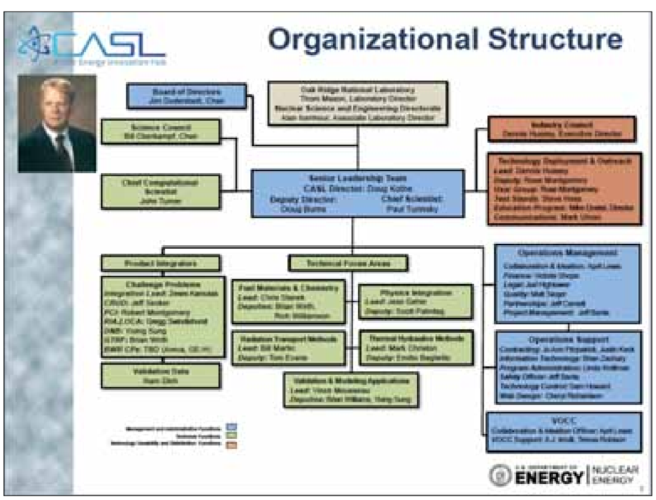


NERS Bill Martin as CASL Scientist

NERS Ed Larson as CASL Scientist

The CASL Energy Innovation Hub

CASL partners

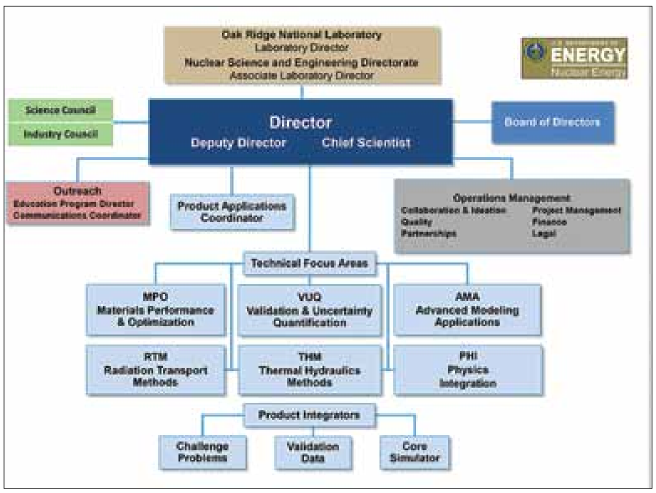


CASL organizational structure

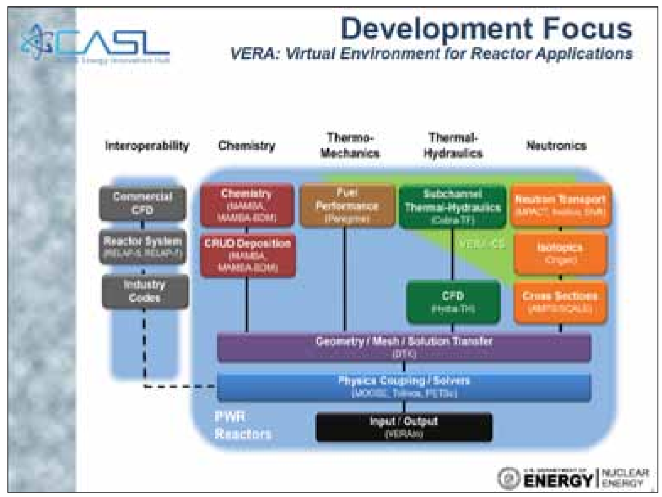
CASL cescription

centerpiece of the CASL VERA core simulator. MPACT has provided pin-resolved detail for the core neutronics simulation and has enabled CASL to address some of the most difficult reactor operational and safety problems encountered in the existing fleet of LWR reactors. Researchers at several national laboratories and in industry have also begun to use the high-fidelity capability in MPACT to improve the design and analysis of the next generation of power reactors.

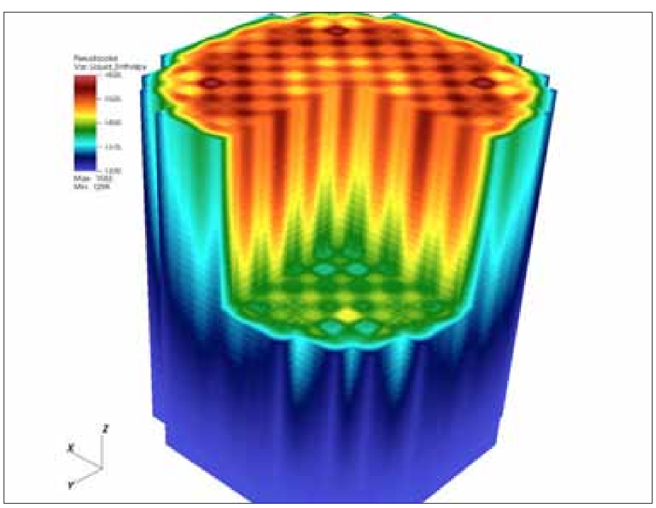
At the end of its projected decade-long activity in 2020, CASL will have developed, assessed, applied and broadly deployed a comprehensive collection of M&S technologies — in one integrated virtual environment for reactor applications. These technologies will address many current and emerging challenges and opportunities for the nuclear industry. With more detailed analyses now possible due to advances in high-performance computing, science-based M&S models will support enhanced understanding for improved designs and materials. Proactive extensions of VERA to pressurized water reactors, boiling water reactors and integral pressurized water reactors will have been realized and deployments to nuclear vendors and utilities as well as the M&S and HPC communities will have taken place. Through these applications and deployments, the CASL technology will demonstrate its capability to improve the cost-effectiveness of nuclear energy generation via design efficiencies, decreased



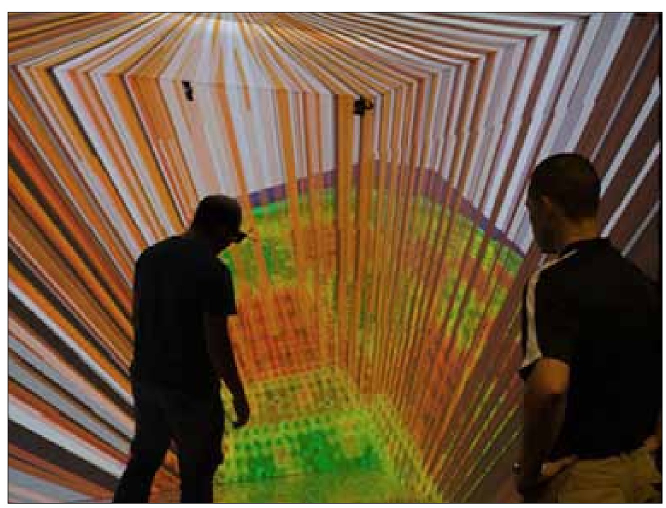
Oak Ridge Project management team



VERA Reactor Simulator

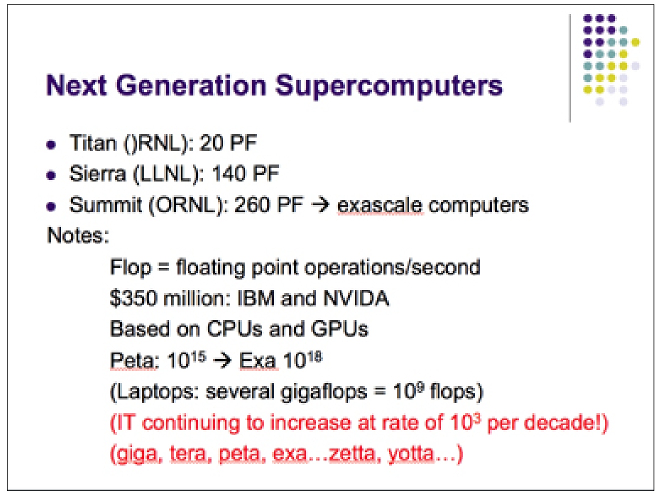


Reactor core calculations



Virtual reality core analysis

Titan Supercomputer (ORNL)



Next Generation Supercomputers for CASL

Summit Supercomputer (ORNL)

Briefing Secretary of Energy Ernie Moniz

design-iteration cycle time and enhanced engineering creativity. With early adoption and technology transfer to the nuclear energy community via the use of industrial test-stands and broad releases of new modeling and simulation technology, CASL M&S technology — able to execute on computer platforms ranging from small computing clusters to DOE's largest advanced future exascale-class platforms — is envisioned to be a transformative technology. It no doubt will lead and inform nuclear energy industry capability well into the future.

50th Anniversary of the Department

The Department celebrated its 50th anniversary in 2008 and hosted a gala event in the University's Michigan League ballroom. Many of NERS' most distinguished graduates returned for the occasion, which was led by Department Chair William Martin along with several previous chairs, including Glenn Knoll, John Lee, Gary Was and future chair Ron Gilgenbach. A brief history of the Department over its first 50 years is included in Appendix E.

The Department of Nuclear Engineering and Radiological Sciences
on its 50th Anniversary

Bill Martin, Chair

Honoring Pam Derry

A Celebration of 50 Years of Leadership in Nuclear Engineering and Radiological Sciences

Glenn Knoll

Valentin Jordanov and Gary Was

Bill Martin, John Engdahl, and Anne Duderstadt

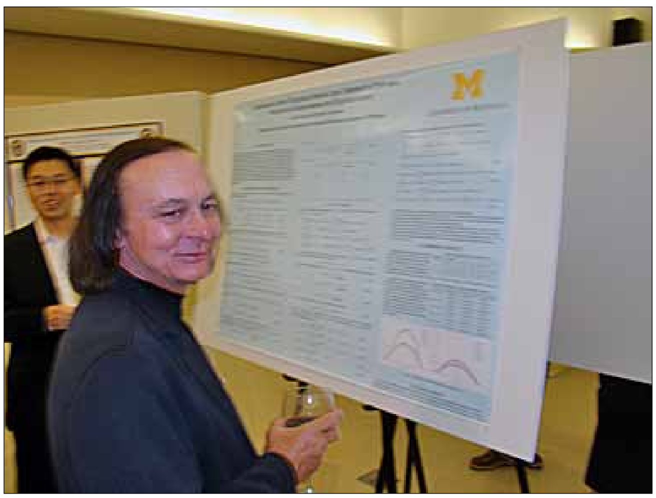
Sid Yip

Jim Fici, Sid Karen, and Michel Mirkovitch

Tom Sutton

Michel Mirkovitch and Ziya Akcasu

Bill and Diane Price and Sid Karin

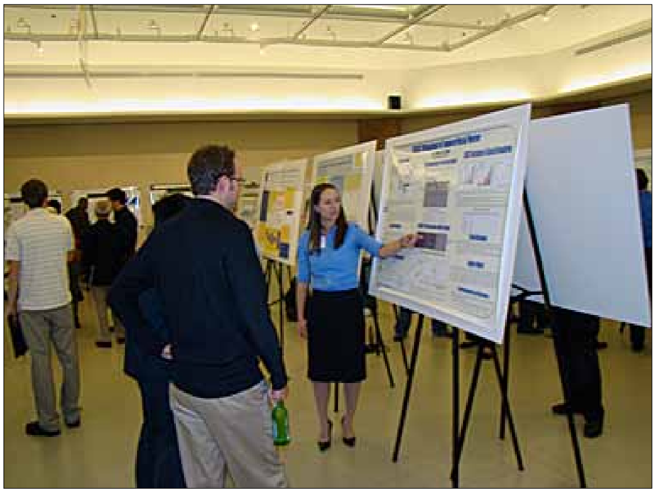


Forrest Brown

Jim Rathkopf and Mary Beth Ward

Pat Martin, Lee Ann Was, Anne Duderstadt

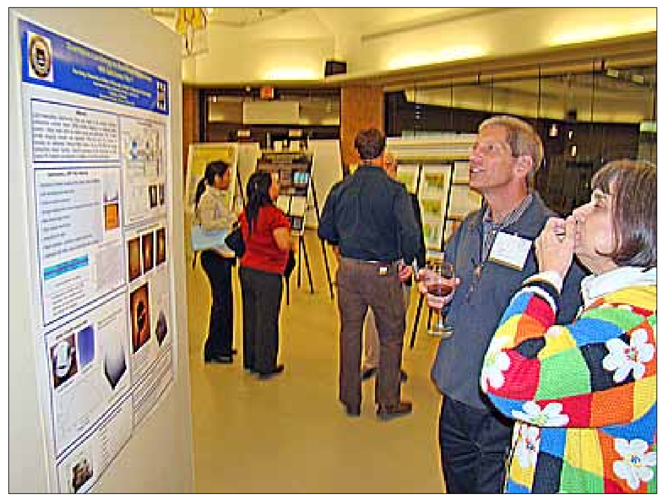
Paul Rockett



NERS displays

NERS alumni

Ron Fleming and Sid Karin



Gary Was and Anne Duderstadt

Refreshments

Performance by the Friars

The James and Anne Duderstadt Center

Student activities

The dedication

Anne and James Duderstadt

24 hours a day, 7 days a week, all year long

But the students have another name

The Neighbor Next Door to NERS...

Chapter 8

The 2010s: Providing Leadership for the Nation

The anticipated expansion of nuclear power during the 2000s succumbed to the development of gas shale fracturing and the high cost and time required for nuclear plant construction. The Department, however, continued to thrive as new faculty were hired, new programs were launched and major new research facilities were developed by the new chair, Ron Gilgenbach, to replace the nuclear reactor laboratory.

Poised for Growth

In its first 50 years, the UM NERS department had made major strides on many fronts, demonstrating national and international leadership in education, research and experimental facilities in nuclear engineering's four major areas of excellence, with application to an increasing number of fields.

Beginning in 2010, during the chairmanship of Professor Gilgenbach, the Chihiro Kikuchi Collegiate Professor, the NERS department embarked on a period of remarkable growth in faculty and facilities, further reinforcing its reputation and paving the way for continued leadership. Externally funded faculty research reached some $24 million per year during this period. Several new hires further broadened and deepened research and educational activities throughout the Department. Growth will continue, with faculty searches underway and plans in place for a major hiring program between 2015 and 2020 in all four major areas of NERS excellence.

New Faculty

The expanding activities of the Department justified the addition of new faculty members. In 2011, Annalisa Manera joined the faculty from research positions in

Ron Gilgenbach. NERS chair

reactor physics and systems behavior in Switzerland. Her particular interests were in experimental studies of two-phase flow, thermal-hydraulics, computational fluid dynamics and multi-phase methods for power reactor safety analysis. She quickly began to initiate courses, developing a research program in thermal hydraulics and building the experimental facilities to support her work, creating the new Computational and Experimental Thermal Hydraulics Laboratory.

The research group led by Professor Xiaodong Sun, hired in January 2016, focuses on nuclear reactor thermal hydraulics and safety, primarily in two broad areas: gas-liquid two-phase flows and thermal hydraulics in advanced nuclear reactors. In the two-phase flow area, research has been conducted in two-phase flow modeling and simulation, interfacial area transport equation development, microgravity two-phase flows, and liquid turbulence measurements in two-phase flows. Currently, Sun's group is investigating post-critical heat flux (CHF) heat transfer at high-pressure and high-flow conditions for LWRs in collaboration

Fei Gao

Igor Jovanovic

Xiaodong Sun

Annalisa Manera

Brian Kiedrowski

Martha Matusak

with the U.S. Nuclear Regulatory Commission. To assist the validation of advanced reactor thermal-hydraulics and computational fluid dynamics codes, Sun's group has been developing extensive two-phase flow experimental databases.

In the area of thermal hydraulics of advanced nuclear reactors, Sun is conducting research to support the development of high-temperature gas-cooled reactors (HTGRs), fluoride salt-cooled high-temperature reactors (FHRs) and molten salt reactors (MSRs), primarily with support from the U.S. Department of Energy. More specifically, he is carrying out work in high-temperature compact heat exchangers, heat and fluid transport phenomena associated with HTGRs, and passive decay heat removal systems for FHRs and MSRs, as well as tritium transport and mitigation in FHRs and MSRs. A high-temperature fluoride salt test facility (shown in figure 1) and a high-temperature helium test facility have been designed and constructed to support research and development activities for FHRs/MSRs and HTGRs, respectively.

Igor Jovanovic arrived in 2016 to lead the Applied Nuclear Science Group (ANSG), which conducts research in two main thrust areas. The first area includes radiation detection and remote sensing, where the objective is to develop innovative devices and techniques to address the challenges in nuclear security, proliferation and safety as well as in environmental and fundamental science. The second thrust area includes intense laser science and technology, where the group's research is focused on developing the technological and scientific foundation for use of intense ultrafast lasers in science, industry and security. The ANSG manages two laboratories, the Neutron Science Laboratory (NSL) and the Applied Nuclear Science Instrumentation Laboratory (ANSIL). In addition, the ANSG is heavily involved in research at the Center for Ultrafast Optical Science (CUOS).

Fluoride test tacility (Sun)

High-Temperature Helium test facility (Sun)

Future Neutron Science Laboratory (Jovanovic)

Applied Nuclear Science instrumentation (Jovanovic)

Brian Kiedrowski arrived from Los Alamos National Lab in 2014. With a doctorate from the University of Wisconsin, he brought strong support to the NERS department's computational efforts, with research in general purpose Monte Carlo radiation transport methods and software development. His specific interests are in nuclear criticality, critical experiment design, sensitivity and uncertainty, adjoint and hybrid methods, time-dependent transport and kinetics.

Fei Gao brought additional strength to the Department's materials science activities, arriving at UM NERS in 2014 from his previous position as chief scientist at Pacific Northwest National Laboratory. Gao's interests included research on ion-solid interactions and radiation effects in ceramics and reactor materials, interfacial and nanostructure evolution of semiconductors, radiation detector materials and development and application of multi-scale computer simulation for materials modeling. Of particular interest are practical concerns, such as the degradation of spent fuel canisters; swift heavy ion damage in materials; ceramics for nuclear waste forms, fuels and fusion reactor applications; and radiation response and signal generation in detector materials.

An earlier PhD from the Departments radiation health physics activities, Martha Matusek, returned as a faculty member in 2015 to start a Rackham Certificate program for the Ph.D. in Medical Physics. Her strong background and experience in treatment planning and optimization for external beam radiotherapy and radiation oncology were well suited to expanding the Department's activities in this important area. She was

Ryan McBride

Won Sik Yang

joined by Associate Professor Kristi Brock-Letherman in this effort, although she later left the Department for a position at the MD Anderson Cancer Center in 2016 (retaining a position as an adjunct faculty member.

Associate Professor Ryan McBride joined the Department in 2016 after eight years at Sandia National Laboratories. His research is conducted in the Plasma, Pulsed Power, and Microwave Laboratory (PPML) using pulsed power technology to generate very fast and very power electromagnetic fields. These fields are used to compress matter to extreme states, which include the plasma state, are characterized by material pressures exceeding one million atmospheres, temperatures exceeding one million degrees Kelvin, and material densities exceeding solid density. Applications of these experimental capabilities include nuclear fusion, radiation source development (neutron radiation, ion beams, gamma rays and x-rays), material properties and strength measurements, and laboratory astrophysics experiments (i.e. laboratory experiments that can help us better understand powerful astrophysical phenomena occurring in faraway locations throughout the universe).

McBride is also looking into ways of applying modern pulsed power architectures (linear transformer drivers, or LTDs) to the generation of high-power microwaves. The electrical pulses generated by pulsed power machines often consist of voltages on the order of millions of volts, electrical currents on the order of millions of amperes, and electrical powers on the order of trillions of watts. The duration of these pulses is usually on the order of one billionth of a second to one millionth of a second. Currently, he is conducting research on two LTD facilities in the PPML: the 200-kV, 1-MA, 0.2-TW, 100-ns MAIZE facility and the 800-kV, 200-kA, 0.1-TW, 100-ns BLUE facility (see photos). Additionally, McBride continues to collaborate with researchers at Sandia National Laboratories, where experiments are conducted on the 4-MV, 26-MA, 80-TW, 100-ns Z pulsed power facility, the world's most powerful pulsed power device.

The most recent arrival to the NERS faculty, in 2017, was Won Sik Yang, who came from positions at both Argonne National Laboratory and Purdue University. Yang's research interests in nuclear reactor physics, computational methods for reactor analysis, reactor core design, fuel cycle analysis, fast reactors, accelerator driven systems and analytic methods, such as sensitivity analysis, cross-section processing, stability analysis and reliability analysis, are important in sustaining and furthering the Department's research efforts in nuclear reactor science and engineering.

Facilities Expansion

A comprehensive research lab space analysis and reassignments in NERS led to the expansion of the Michigan Ion Beam Laboratory (MIBL) to support a $5 million U.S. Department of Energy (DOE) Integrated Research Project (IRP), led by MIBL director Gary Was. The goal of the IRP is to accelerate reactor materials development for advanced nuclear energy. The MIBL was closed late in 2013 for a complete renovation and update and re-opened in 2015 as the country's only triple-

The Maize Pulsed Power LTD

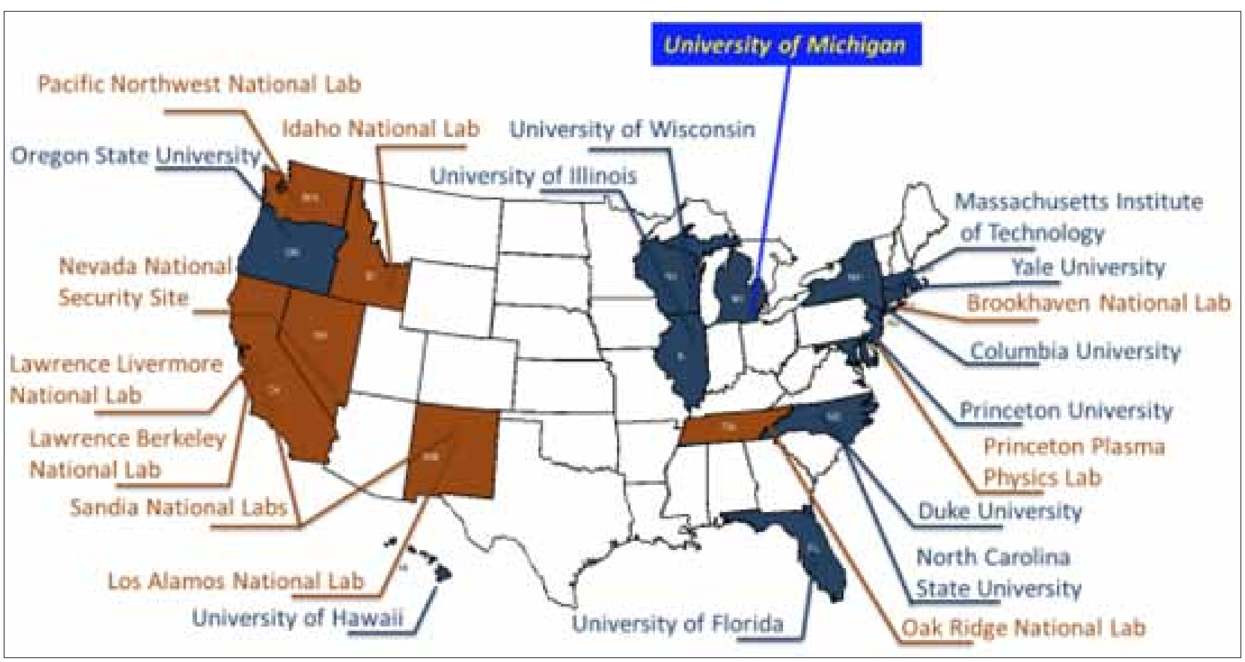
The Blue Pulsed Power LTD

beam accelerator facility.

In March 2016, Nuclear Science User Facilities conducted a review of ion beam facilities in the United States. Of the 16 facilities, including eight national laboratory facilities, the MIBL was selected as the top laboratory in the nation. The MIBL has since installed a $2 million transmission electron microscope that will be coupled to two ion beam lines, providing the capability to observe radiation damage in materials in real time.

Since the discovery of fission, nuclear chain reactions and nuclear weapons, preventing the spread of nuclear weapons has become a top priority for our nation and the world. The international community has developed several treaties that have been designed, negotiated and entered into to curb the expansion of nuclear capabilities. Nevertheless, there are states that may be pursuing elements of an overt or covert nuclear weapons program, with North Korea being a recent example. New science and technology developments are needed to verify existing or proposed treaties and to ensure that nuclear weapons are never used again.

In 2014, Professor Sara Pozzi led the formation of a major research program, the Consortium for Verification Technology (CVT), a large consortium of 12 uni-



Consortium for Verification Technology

NERS Students at the Fuqing Nuclear Power Plant construction site

versities and 9 national laboratories working together to develop new technologies for nuclear treaty verification and to train the next generation of nuclear scientists and engineers. The CVT is funded by a five-year, $25 million grant from the DOE National Nuclear Security Agency.

Scholarships and Fellowships

An ever-expanding network of generous and supportive alumni enable much of the Department's work and help create a vibrancy that enlivens education, scholarship and research. A number of new scholarships and fellowships were initiated by donors over the decade (a list appears in Appendix D). In addition to endowing professorships, fellowships and scholarships and award funds, alumni and friends of the NERS department have also endowed lecture series. These include the Glenn F. Knoll Lecture in Nuclear Engineering and Radiological Sciences and the Richard K. Osborn Lecture. The Knoll lectureship was established in 2014 by the family of the late Professor Emeritus Glenn Knoll. Knoll lecturers have included:

- William Moses, Lawrence Berkeley National Laboratory (2015)
- David Kay, Retired, IAEA (2016)
- Lothar Struder, PNSensor GmbH, Germany (2017)

The Osborn lecture was established in 2011 by a student and, later, collaborator of Osborn's, Sidney Yip. Presenters have included:

- Ju Li, MIT (2011–2012)
- James Duderstadt, UM (2012–2013)
- Jack Carpenter, Argonne National Laboratory (2013–2014)
- Paul Turinsky, North Carolina State University (2014–2015)
- Brian Wirth, University of Tennessee, Knoxville (2015–2016)
- Ziya Akcasu, UM (2016–2017)
- Tom Sutton, Naval Nuclear Laboratory (2017–2018)

Such a strong past has gifted the University of Michigan Department of Nuclear Engineering and Radiological Sciences with some $14 million (from 2010 to 2018), ensuring its enduring qualities and ongoing curiosity, discovery and growth.

International Activities

The 2010s also brought growth in the Department's activities abroad. Cooperative efforts with Chinese nuclear programs that had first launched in the late 1990s continued with a series of Summer Schools on Clean Energy organized annually by Professor Lu-min Wang beginning in 2011. China's rapid development of nuclear power provided an important resource to nuclear engineering and nuclear engineering education with Gen III nuclear power plants. With the assistance of Ron Fleming, the summer schools were first developed at Xiamen University with a UM grant from the Global Intercultural Experience for Undergraduates program but soon became one of the regular summer programs sponsored by the College's Office of International Programs in Engineering.

To date more than 100 UM students have attended these six-week summer schools, including more than 20 students from NERS. Eight NERS faculty have also attended and given lectures on reactor safety and related subjects.

As part of the summer schools, students have had the unique opportunity to visit nuclear reactor construction sites in China, including Daya Bay, Sanmen, where two Westinghouse AP1000 Generation III reactors have been under construction, and Fuqing, where six pressurized water reactors of two different Chinese designs have been under construction. On each of those sites, construction of the reactors started in successive six-month to one-year intervals, giving students a rare opportunity to see the progressive stages of reactor construction. In summer 2016, the Department hosted 24 undergraduate students from Xiamen University in return.

More than 20 College of Engineering students who attended the summer schools at Xiamen University have also participated in six-week internship programs at Shanghai Nuclear Energy Research and Design Institute, which is responsible for completing the final engineering design of the AP1000 reactors in China. The NERS department has two current programs with the Shanghai Institute and Harbin Engineering University for education and basic research in nuclear science and engineering to train both students and visiting scholars from these institutions. The programs are supported by over $2 million in research grants and training fees provided by Chinese institutions.

From the Ford Nuclear Reactor to the Nuclear Engineering Laboratory Building

The long odyssey in converting the Ford Nuclear Reactor to state-of-the-art research laboratories — known as the Nuclear Engineering Laboratory building (NEL) — began with the decision to decommission the reactor in 2002. The reactor was shut down on July 3, 2003. A long decommissioning process began that took some 10 years at an estimated cost of $20 million. As the reactor was dismantled, components were shipped to various nuclear waste facilities around the country.

In 2010, Department Chair Gilgenbach performed a comprehensive space analysis and developed a plan to accommodate the major increase in faculty and research activities. In addition to consolidating space in the MIBL to permit installation of a third accelerator, Gilgenbach identified the former Ford reactor site as an ideal building for nuclear research given its heavily-shielded walls and proximity to the Phoenix Memorial Laboratory and the Cooley Building, where all NERS offices were housed.

The College of Engineering contracted with architectural firm SmithGroupJJR to perform a preliminary design study. Gilgenbach participated in these studies, which led to the initial design drawings. Shortly thereafter, Gilgenbach met with alumnus Dr. J. Robert Beyster and presented the idea of building an accelerator facility for homeland security and nuclear nonproliferation experiments in place of the reactor. Dr. Beyster was enthusiastic about the project and pledged $5 million to the project if College of Engineering Dean Dave Munson would commit the balance. Dean Munson agreed, and the project began to move forward.

At their September 2013 meeting, the UM Regents approved the Ford Nuclear Reactor Renovation Project with Smithgroup JJR as the architect. The facility was estimated to provide 20,500 gross-square-feet in a four-story building. The fourth floor was originally occupied by the cooling towers of the reactor. At its December 2013 meeting, the UM Board of Regents approved the $11.4 million budget.

The original completion date of the NEL was estimated to be in the fall of 2015. Gilgenbach and NERS faculty laboratory directors met often with SmithGroupJJR architects and engineers to design their dream labs. After a bidding process, Spence Brothers was chosen and approved as the general contractor for the building. During the preceding years, UM had filed decommissioning applications with the U.S. Nuclear Regulatory Commission (NRC) and performed required radiation measurements and remediation. Analysis of additional soil samples and NRC approval of these decommissioning applications took an additional year, delaying the start of construction.

A wall-breaking ceremony was held in September 2015, with construction commencing shortly thereafter.

At this ceremony, Gilgenbach stated: "…this new building will lead the Nuclear Engineering and Radiological Sciences Department into a new era and explore the use of ionizing radiation for a range of applications, from homeland security to nuclear nonproliferation, radiation detectors and nuclear reactor safety."

The demolition process of the nuclear reactor building was more difficult than anticipated, with five-foot-diameter saw blades running continuously for months to extract the one-to-three-foot-thick structural and shielding walls left from the reactor. New window openings were also sawed vertically in the west and north sides of the building, with four additional windows cut on the east side. It was estimated that the demolition phase took 80% of the total project time, although demolition costs were disproportionality lower than construction costs.

The reactor pit was filled with 112 cubic yards of concrete pumped into the building in early January 2016. Steel I-beams were bolted to the reactor walls to construct the structure of the second and third floors. Corrugated steel sheets were installed over the I-beam structure, covered by rebar and foot-thick concrete. Metal studs and drywall were added to define the laboratories and offices.

The basic design of the NEL building took maximum advantage of the existing reactor building structure. For example, Professor Manera's thermal hydraulics and high-resolution imaging laboratory was located on the first floor, with grates in the floor directly over the full basement. This permitted the largest vertical distance (26 feet) for development of flows in hydraulics experiments. This laboratory was also located below grade to enable x-ray radiography experiments on two-phase flows. Pumps and steam generators are located in the basement in which electrical conduits deliver copious electrical capacity.

Professor Pozzi's Detection for Nuclear Nonproliferation Laboratory incudes a radio-frequency linear electron accelerator facility (Varian) capable of energies up to 9 MeV. This facility will be utilized to generate gamma rays and neutrons. For shielding reasons, the accelerator is located in a section of the first-floor laboratory that is fully underground. Additional shielding was added to the ceiling of the accelerator room to reduce skyshine, and the location of the accelerator itself was selected to shield radiation from reaching other areas.

Construction was completed on schedule, in April 2107. Faculty moved into their new laboratories shortly after. The new Nuclear Engineering Laboratory building includes the Detection for Nuclear Nonproliferation Laboratory and the Consortium for Verification Technology (both led by Professor Pozzi), the Experimental and Computational Multiphase Flow Laboratory (Professor Manera), the Applied Nuclear Science Group (Professor Jovanovic), a new laboratory for investigating metastable materials (Professor Michael Atzmon), and the Glenn F. Knoll Nuclear Measurements Laboratory. In this lab, professors Zhong He and David Wehe will continue their work developing advanced gamma ray cameras.

The NEL also contains flexible laboratory space, currently occupied by Presidential Postdoctoral Fellow Patricia Schuster (scintillator research), and office space for research scientists, faculty and graduate students. Student and faculty meeting spaces include The Harold N. Cohn Conference Room, overlooking the class of 1947 reflecting pool, and The John S. King Student Collaboratory.

Alumni, their families and friends of the department helped realize the vision. In addition to J. Robert Beyster's initial donation, several other generous donors contributed. The Glenn F. Knoll Nuclear Measurements Laboratory was made possible by a major gift from Gladys Hetzner Knoll. The John F. King Student Collaboratory was made possible by an initial contribution from former UM NERS Professor Sidney Yip with Francie King and many friends, colleagues and former students of Professor King. The Harold N. Cohn Conference Room was supported by a gift from the Cohn family.

By spring 2017, the site of the old Ford Nuclear Reactor had been rebuilt to continue its legacy. At the dedication event, Gilgenbach noted, "All of these laboratories will continue the great research tradition of the Michigan Memorial Phoenix Project, a war Memorial to those 579 Michigan men and women who sacrificed their lives in World War II. Like the mythical Phoenix, these new laboratories have risen above the former nuclear reactor site."

Ready to break down the wall

Gladys Hetzner Knoll with other dignitaries

Ron Gilgenbacnh and Dave Munson

Sid Yip breaks the wall

Meeting in the Phoenix Energy Institute

A dinner to celebrate the event

Nuclear Engineering Laboratory "Wall Breaking" Event

Earlier Phoenix Memorial Laboratory

Pumping concrete into NEL

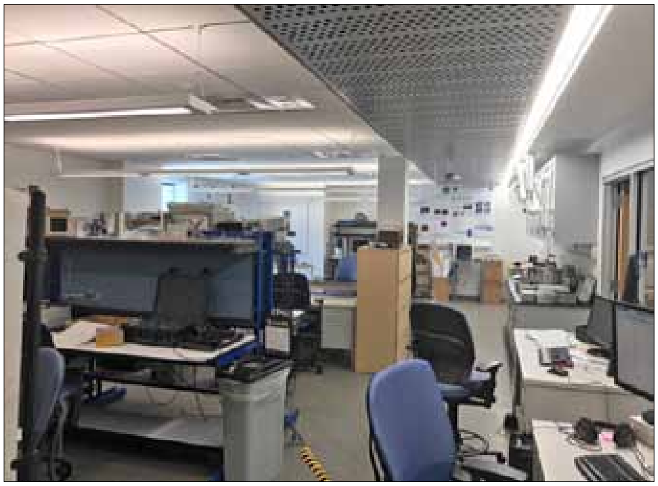
Filling the reactor pit with concrete

Constructing floors in NEL

Steelwork for NEL Floors

Detection for Nuclear Nonproliferation Lab

Some Interior Scenes of the New Nuclear Engineering Laboratory



Glenn Knoll Nuclear Measurements Laboratory

Student Collaboratory

MMPP and NEL

Linear Accelerator Laboratory

Graduate Student Offices

Some Interior Scenes of the New Nuclear Engineering Laboratory

The New Nuclear Engineering Laboratory

NEL from the Reflecting Pool Side

Chair Ron Gilgenbach leads Dedication

Dedication of the NEL

NEL Dedication Audience

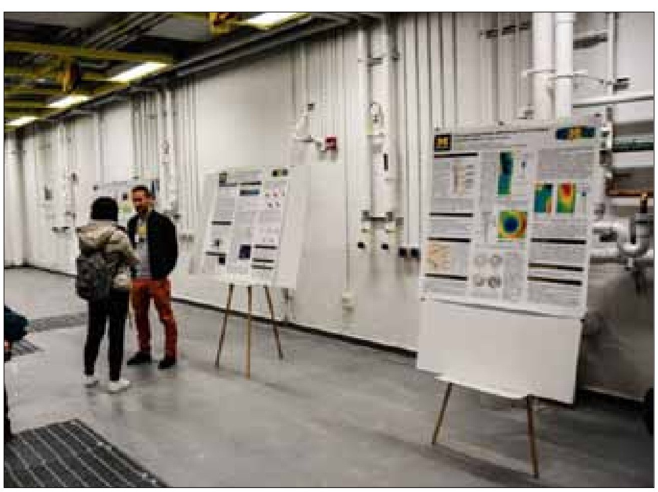
Dedication of the Nuclear Engineering Laboratory

Getting ready to cut the ribbon

Glenn Knoll
Achievement Display

The Knoll Family: Gladys, Tom, John, and Peter

Gladys Knoll and Ron Gilgenbach



NEL Dedication Display

NEL Dedication Dinner

Dedication of the Nuclear Engineering Laboratory

Faculty and Student Awards and Honors

The Department's history remains a palpable source of inspiration as bright, accomplished new faculty carry out their work and continue making discoveries and contributions for which they, too, are being recognized. Throughout its history, the UM NERS department has seen its faculty and alumni celebrated with a number of prestigious awards. A complete list of faculty awards and honors has been provided in Appendix D.

In addition, an ever-expanding network of generous and supportive alumni enable much of the Department's work and help create a vibrancy that enlivens education, scholarship and research. Of major importance has been the funding of numerous scholarships and fellowships for students, distinguished lectureships to honor alumi of the Department, and endowments to support various faculty roles such as the Department Chair. The current list of such awards is also provided in Appendix D.

A Final Salute to the Future

In fall of 2017 at the annual fall kickoff of the academic year for the Department of Nuclear Engineering and Radiological Science, Gladys Knoll announced to Chairman Ron Gilgenbach her intent to endow the Department Chair faculty position for the future. Such a commitment now only demonstrates once again the remarkable impact the Knoll family has had on the Department, but it provides a strong vote of confidence in its future.

The Ceremony celebrating the endowment of the Glenn F. and Gladys H. Knoll Department Chairmanship with Chair Ron Gilgenbach, Gladys Knoll, and Dean Alec Gallimore.

Chapter 9

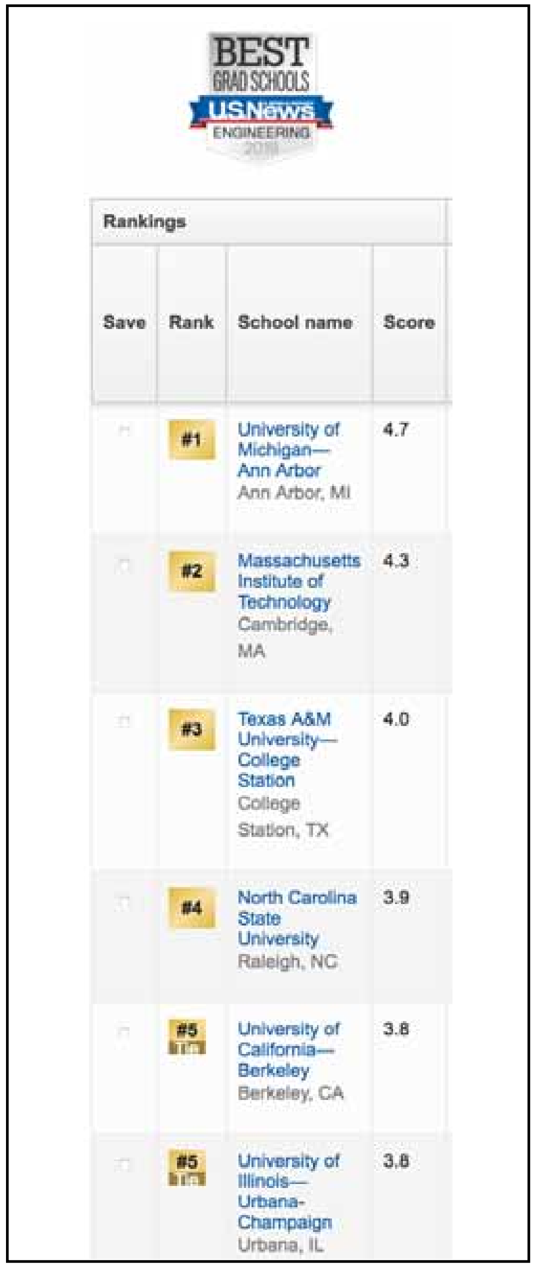
The Nuclear Engineering and Radiological Sciences Department of Today

The mission statement of the Department of Nuclear Engineering and Radiological Sciences is "To educate students to become outstanding engineers and scientists in nuclear engineering and radiological sciences and to develop the future practitioners and leaders in research, industry and education both within the U.S. and internationally, and to strengthen our national and international reputation as the leading educational and research institution in nuclear engineering and radiological sciences." For some 60 years, the NERS department has strived, successfully, to achieve this mission, maintaining #1 rankings from U.S. News and World Report in eight out of the nine years between 2010 and 2019.

Over the past decade, the NERS department has experienced a period of major expansion in several areas: Faculty hiring (seven new faculty), laboratory and office space development (approximately 20,000-square-feet of new space, including the new $13 million Nuclear Engineering Laboratory Building reconstructed from the former Ford Nuclear Reactor space), fundraising (some $14 million) and research funding ($24 million for FY17). Aggressive hiring has addressed the issue of adding sufficient fission reactor faculty (four hires) to teach undergraduate classes as the retirement of several faculty draw near, with single faculty hires in computational materials, plasma/fusion and measurements areas.

Undergraduate enrollment levels are rising despite the economic challenges currently facing nuclear power. Graduate enrollment is near an all-time high (136). In collaboration with the Radiation Oncology department, the new postdoctoral Medical Physics Program has earned accreditation with a PhD and MS program application in process.

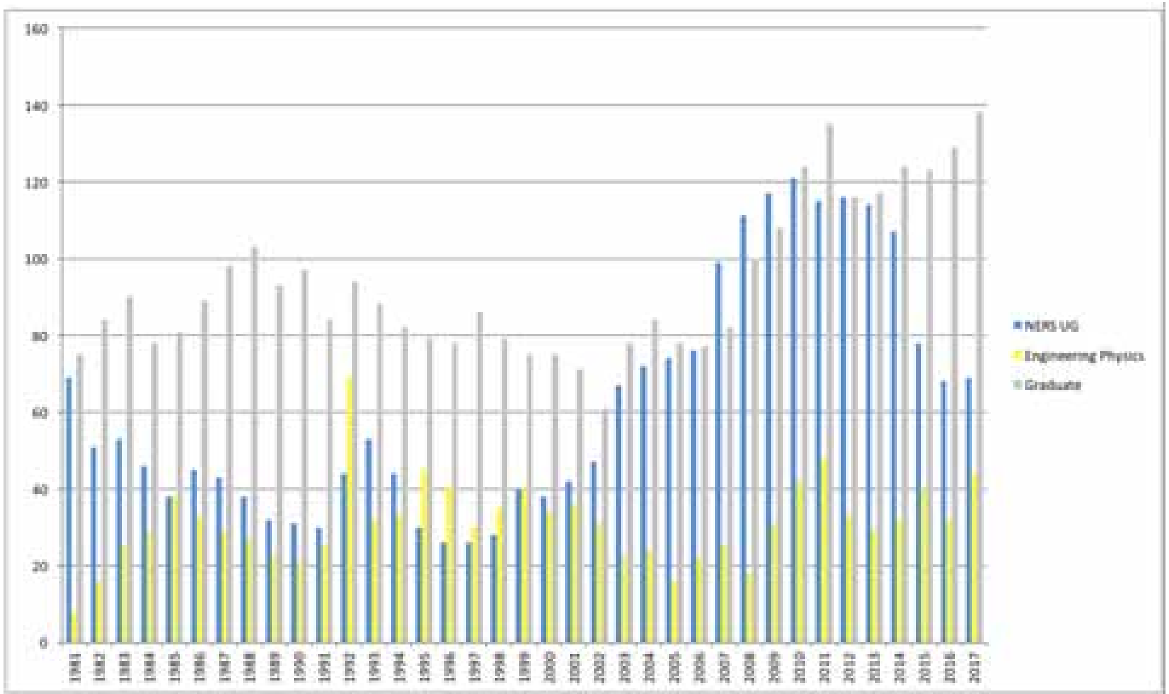
The following summary of the current status of



Rankings

Save	Rank	School name	Score
	#1	University of Michigan—Ann Arbor Ann Arbor, MI	4.7
	#2	Massachusetts Institute of Technology Cambridge, MA	4.3
	#3	Texas A&M University—College Station College Station, TX	4.0
	#4	North Carolina State University Raleigh, NC	3.9
	#5 Tie	University of California—Berkeley Berkeley, CA	3.8
	#5 Tie	University of Illinois—Urbana-Champaign Urbana, IL	3.8

Nuclear Engineering Graduate Programs
2019 U.S. News and World Report Rankings



NERS Undergraduate and Graduate Enrollments

the Department draws heavily from its most recent strategic plan.

Instructional Activities

Undergraduate Programs

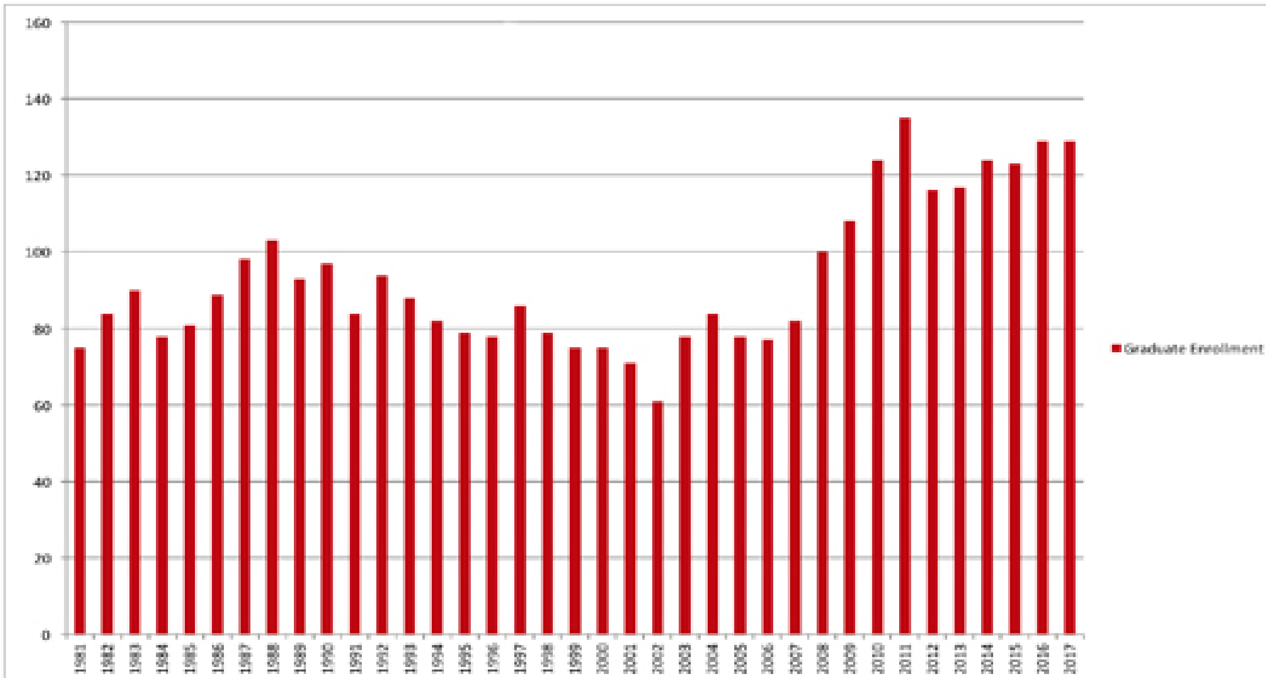
Since 2006, undergraduate enrollment has increased from about 75 to 120, peaking in 2010. There is strong indication of deleterious impacts on enrollment due to the Three Mile Island (1979), Chernobyl (1986) and Fukushima (2011) accidents. Although the healing time for such events is typically a decade or more, six years after Fukushima it appears that the Department has reached a new equilibrium at around 70 students, offset, somewhat, by an increase in Engineering Physics enrollment. However, the Westinghouse bankruptcy and cancellation of two of four AP1000 reactors under construction in the United States may also affect undergraduate and graduate enrollments.

Because students must apply to the College of Engineering as a “general engineering” student and then self-select into a major once they matriculate, the Department has increased its efforts to reach out to first-year students in the first term of their enrollment. Undergraduate scholarships have been, historically speaking, a good, low-cost method of attracting quality students to NERS, and the number of undergraduate scholarships has increased dramatically over the past seven years (see Appendix D for a list of scholarships and fellowships).

In addition to freshman admissions, the Department is striving to increase diversity through transfer admissions from community colleges and historically black colleges and universities. The College is proactive in this area, and NERS joined in developing programs to expand the diversity of the undergraduate student body. Taking advantage of University diversity programs, this effort has led to the successful enrollment and graduation of several students. The Department’s advising staff is paying close attention to the special needs of diverse demographic groups to ensure their success.

Graduate Programs

As the top-ranked nuclear engineering graduate program most years during much of its history, NERS has successfully attracted many outstanding graduate students in nuclear engineering. The overall



NERS Graduate Enrollments

performance of NERS graduate students during their PhD research has frequently been noted as one of the strengths of the program by the Rackham Graduate School. In the survey conducted by Rackham in 2016, current NERS graduate students reported being very satisfied with the graduate program and very comfortable with the sense of community among the students, faculty and staff in the Department that has helped them grow as academics.

The overarching goal of the graduate program is to continue to educate the next generation of leaders in the nuclear and radiological sciences through cutting-edge research projects and delivery of academic courses. As a result, the Department strives to retain the top ranking among U.S. nuclear engineering programs. One of the most important outcomes of achieving this goal will be the Department's ability to recruit top graduate students. This will be particularly important over the next several years as greater emphasis is placed on the quality of the graduate student body. This is in part due to the continued implementation of a guaranteed five-year funding program for PhD students and the leveling off of graduate program growth.

Today, the graduate program is at a robust 138 students, of which 110 are doctoral students and 28 are Master of Science (MS) students. With the current faculty of 25, this corresponds to an average of approximately 4.4 PhD students per faculty, which exceeds the College average but is consistent with current and expected faculty productivity and the considerable growth in NERS external research funding.

One goal of the NERS graduate program has been to increase MS enrollment, to be consistent with current trends in the College and the overall maturity of the nuclear engineering field. The number of master's students has increased from 16 to 28, and the Department will continue to stimulate growth through the Rackham Bridge to Doctorate and other programs since master's students are typically self-funded.

The Department has also improved the number of female graduate students. That number rose from 16 out of 118 over the past decade to 23 out of 136, or from 13% to approximately 17% of the graduate student population. Greater use of such programs as master's degree fellowships and the Summer Research Opportunity Program to attract diverse students will be part of the NERS graduate recruiting program in the future. Efforts to diversify the student body will also be facilitated by a greater diversification of faculty.

Degrees Awarded

- **Cumulative degrees awarded 1958-2017**
  - 1002 BSE NERS
  - 308 BS Eng Phy
  - 1260 MS/MSE
  - 657 PhD
  - 9 Nuclear Engineer Professional Degrees
- **AY 2016-2017 Degrees**
  - 24 BSE NERS
  - 8 BS Eng Phy
  - 29 MS/MSE
  - 15 PhD
- **Current enrollments**
  - NERS Undergraduate: 69
  - EP Undergraduate: 44
  - Graduate: 138

Research Activity

External funding in the Department has more than tripled over the past decade, with the current average per faculty of close to $1 million. Because the majority of sponsored research in the department is supported by funds from the federal government, specifically from the U.S. Department of Energy, it is reasonable to anticipate some volatility in overall funding level. More specifically, there are indications at the time of this writing that Nuclear Energy University Program funding may decrease, whereas National Nuclear Security Administration funding may increase. Nonetheless, the current funding level appears more than sufficient to sustain the current number of graduate student research assistant positions, and it is anticipated there will be a modest increase in the PhD program due to recent faculty hires.

The NERS department historically has been recognized for its excellence in four traditional areas: fission reactors, fusion/plasmas, nuclear measurements and nuclear materials. Recently, research challenges have become increasingly interdisciplinary with respect to both research and teaching, and the future of NERS' excellence requires precisely this type of cross-disciplinary approach.

To this end, the Department has identified four areas of interdisciplinary activities, in a sense "grand challenges," and formed teams of faculty that work across the four traditional areas:

Sustainable Energy: Fission, safety, CASL, materials, measurements, fusion, sustainability, economics

Nuclear security and defense: homeland security, nuclear non-proliferation, nuclear forensics, antiterrorism

Environment and Health: used fuel issues, radiological health and impacts, medical applications, plasma medicine, environmental remediation

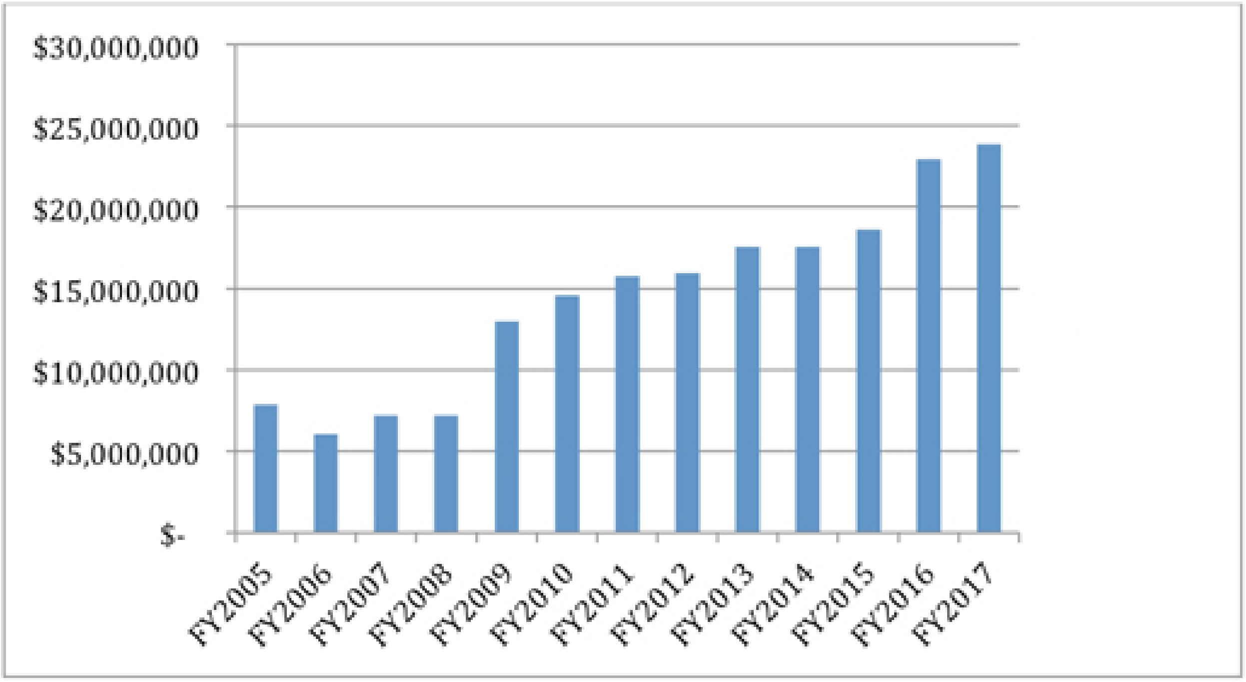
Enabling Scientific Discovery: simulation and modeling, fundamental nuclear, atomic and plasma data measurements.

As each of these new interdisciplinary areas grows, the Department is likely to adopt new administrative and curricular structures that align with these research thrust areas.

Sustainable Energy

A sustainable supply of clean, low-cost energy is essential for the well-being and prosperity of humanity, and the Department has a central role to play in providing the means to develop nuclear technology that can address this supply challenge. The escalating capital costs for large nuclear power plants, the concerns raised by the 2011 Fukushima accident, the current relative inexpensiveness of natural gas and the volatility of electricity pricing because of wind and solar energy all have led to a stagnation of nuclear energy growth in the United States and put existing nuclear power plants at risk.

Keeping existing nuclear power plants open during this economically challenging time will require an emphasis on their continued safe operation as they age. The Department has expertise through the support of two major programs. The Light Water Reactor Sustainability (LWRS) program addresses issues associated with plant life extension, such as stress corrosion cracking in core and ex-core, reactor pressure vessel embrittlement and other potentially life-limiting issues. The Consortium for Advanced Simulation of Light Water Reactors (CASL) addresses the simulation and modeling requirements of the existing nuclear



NERS Research Activity

industry. Specifically, the Department should continue to lead in the development of advanced algorithms and software for reactor physics and play an increasing role in development of these capabilities in thermal hydraulics and fuel performance.

For example, the Department has had recent success in the development of a capability for predicting the buildup of CRUD (Chalk River Unidentified Deposits) in reactor core fuel elements; this research should be expanded and the underlying methods applied to new reactor design and fully integrated into the Department's simulation and modeling portfolio. Additionally, the Department has grown its thermal hydraulic experimental capabilities through recent hiring that supports the efforts within CASL and should create synergies with computational capabilities by informing simulation needs and providing benchmark data. Research on the problem of irradiation-assisted stress corrosion cracking has led to a new theory for its origin, which will be helpful in designing mitigation techniques.

The Department is also well equipped to develop new materials for current and future nuclear energy systems. The Michigan Ion Beam Laboratory (MIBL), currently a participant in the CASL, should continue to provide key experimental data for performance of materials under irradiation and in appropriate thermo-chemical conditions. It will also investigate opportunities for development of new nuclear materials. The Department's recently established capability in computational materials should be further integrated with MIBL and the CASL modeling and simulation efforts in reactor analysis. In the near term, specific focus should be given to development of accident tolerant fuels, which can offer a greater response time in accident conditions. The use of ion beam simulation of reactor irradiations will continue to be aggressively pursued by industry. The Electric Power Research Institute (EPRI) is relying heavily on this technique to screen potentially superior alloys for core component material replacement in its Advanced Radiation Resistant Materials (ARRM) program.

The future energy economy is likely to push nuclear energy toward development of small modular reactors using advanced or non-traditional concepts. There is a corresponding need for advanced modeling and simulation tools that meet the needs of these new designs, which differ from conventional, large light-water reactors. Foremost, the Department should take a leadership role in identifying these needs. In support

Expansion of the Michigan Ion Beam Laboratory

Gary Was explaining the Michigan Ion Beam Laboratory to Governor Snyder

of this, Department should develop expertise in the simulation and modeling of fast reactors. Additional non-traditional reactor technologies may also include: reactors capable of load following, reactors with non-traditional and/or very-high-burnup fuels, gas-cooled reactors (e.g. pebble-bed reactors), reactors with non-conventional coolants (e.g. molten salt, lead-bismuth eutectic), liquid-fueled reactors (e.g., molten-salt-fueled reactors) and alternative applications of nuclear power, such as desalination, synthetic fuels, medical isotopes and energy storage. Most all of these designs will depend on development of materials that can withstand substantially more aggressive conditions relative to water reactors; higher temperature, higher neutron fluxes and fluences, and more aggressive environments.

Nuclear techniques will continue to play a role in other forms of energy generation as well. For example, NERS research into nano-semiconductors for radiation detection involves close collaborations with solar cell researchers who share similar technology goals and material development issues. In addition, radiation sources and detectors are needed to measure fossil plant emissions, critical component integrity and to search for new sources of gas and oil. Even in the area of fossil fuels, nuclear techniques are being developed to nondestructively assess the carbon loading of soils and other indigenous materials.

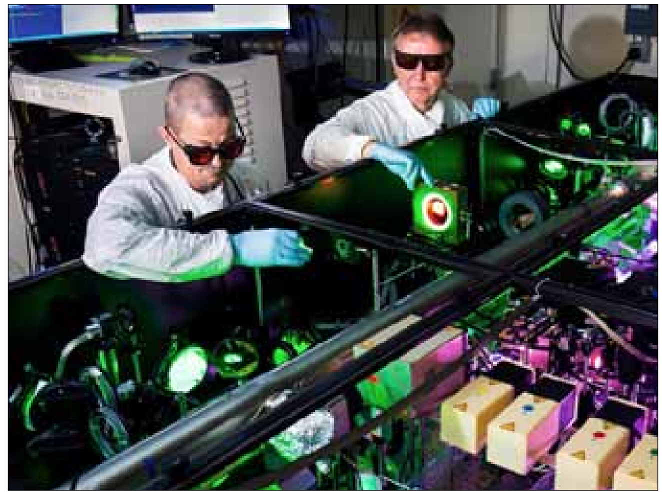
In the area of fission, focus is on succession planning to maintain a critical mass of faculty with demonstrated accomplishments in both the Department's historical strengths in reactor physics and radiation transport and strategic hiring in anticipated growth areas, including advanced reactors, thermal hydraulics and nuclear fuel performance. This is especially important considering Department of Energy/National Nuclear Security Administration funding trends toward megaprojects that cut across disciplines and institutions. Having sufficiently skilled faculty will be vital to securing funding in the future.

Much of the Department's fission research is supported by the CASL program, which has led to achievements including the MPACT radiation transport package, which is central to the radiation transport efforts of the Consortium. CASL has been renewed for a second term of five years, through 2020, but funding is unlikely to continue past this date. It is therefore imperative that NERS, leveraging the innovations from CASL and the expertise of current and future faculty, develop a path forward so research and development may continue following its conclusion.

The NERS department has developed a close relationship with TerraPower and is providing critical data on the behavior of materials proposed for cladding and ducts for its prototype. In fact, this data will be used in support of its reactor license application. The Department should expand its embrace of the innovative spirit exemplified by recently established nuclear energy startup companies, such as TerraPower, NuScale and Terrestrial Energy, so that NERS maintains its leadership role in nuclear energy.

Collaboration among the Department's traditional

The Maize Pulsed Power LTD



HERCULES Laser

areas of excellence is critical to a more integrated and diverse research portfolio. Potential areas of collaboration include:

(1) Fission – Materials: Collaborations leading to the development of new materials for high-radiation environments in fission reactors should continue and be expanded, and new collaborations in fuel performance and nuclear fuel design should be established.

(2) Detection – Fission – Materials: Both analysis of nuclear fission reactors and radiation effects on materials have radiation transport and other simulation capabilities that should be better integrated to address detection needs within nuclear power plants and its fuel cycle facilities, ensuring nuclear safeguards by supporting non-destructive assay techniques and collaborating on relevant non-proliferation needs regarding the nuclear fuel cycle and any other areas where capabilities can be shared.

(3) Plasmas – Materials – Fission: Collaborations in nuclear fusion energy should be established jointly with the materials and plasma areas of excellence. For example, the area of materials performance in high-radiation, plasma-facing environments could leverage existing simulation capabilities within the fission area. Additionally, experimental thermal hydraulics expertise can be applied to fusion reactor design and issues including heat removal for energy conversion and tritium production.

In the area of fusion energy, the Department should continue to support its plasma physics capabilities. Despite many important advances, a fusion energy gain in excess of unity (the condition for break-even) has not yet been demonstrated in the laboratory, let alone in a demonstration plant. However, with Sandia's Z-Machine and the National Ignition Facility currently performing inertial fusion energy experiments and the ITER magnetic confinement facility due to start experiments in the 2020s, fusion is and will remain an important focus of energy research for many years to come. The Department should contribute significantly to this drive for sustainable fusion energy.

Opportunities also exist to grow efforts in materials for fusion reactors. This is a sizeable international effort, and the use of ion beams in the study of fusion materials is well established. The expansion of the capability of the NERS MIBL facility provides an opportunity to make inroads into this field.

The Department is already contributing to fusion sciences in a number of areas. In particular, inertial confinement fusion-related research is a special strength, and efforts should focus on further extending this area. Maintaining departmental leadership in inertial fusion-related facilities, such as the MAIZE Z-pinch, and HERCULES and T-cubed laser systems through upgrades, and acquiring and developing new facilities, such as the recently-acquired BLUE-Ursa-Minor LTD and a high-energy, long-pulse laser system, are crucial. Specific research areas for development include understanding fundamental instabilities under inertial fusion-related conditions, alternative ignition schemes leveraging pulsed-power or short-pulse laser capabilities, diagnostic development for fusion experiments and developing kinetic plasma models for fusion that leverage the substantial transport theory expertise in the Department as a whole.

Nuclear Security, Safeguards, and Defense

The National Academy of Engineering recently identified “preventing nuclear terror” as one of the 12 Grand Challenges for Engineering in the 21st century. New technologies to prevent, deter and, if required, respond to a nuclear attack are urgently needed in the United States and worldwide. Faculty, staff and students in the NERS department are responding to this Grand Challenge through the development of new detection techniques and algorithms for special nuclear material (SNM) detection, characterization and identification. Such techniques are used, for example, to deter the illicit trafficking of SNM by employing them to monitor the shipment of goods and services across borders. Nuclear forensics techniques can be used to characterize pre- and post-detonation debris material following a terrorist incident to aid in attribution of the material. New technologies are being developed to detect the production of SNM and accurately measure their quantities and location within the nuclear fuel cycle.

Related to these efforts, NERS leads a groundbreaking effort to verify nuclear treaties by strengthening the interface among science, novel technologies and policy through the 12-university, five-year Consortium for Verification Technology (CVT), funded by the U.S. Department of Energy/National Nuclear Security Administration. The CVT funds university research with strong ties to nine national laboratories across the country.

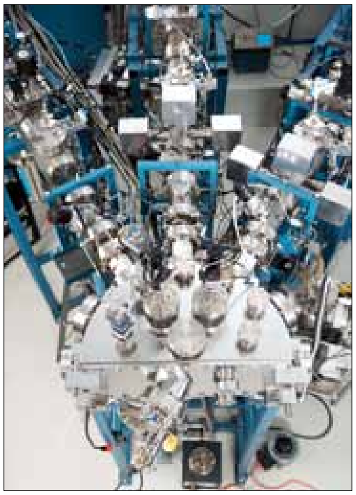
The search for nuclear material, including radioisotope sources and SNM, requires new technologies that allow long-range, standoff detection and are capable of imaging the location of the source of these materials’ passive emissions. Plutonium, for example, emits energetic neutrons from fission as well as abundant gamma rays that can be imaged, effectively pointing to their source. The NERS department is a world-leader in the development of new imaging systems that will enable locating and characterizing a radiation source using a combination of fast and thermal neutron and gamma-ray detectors.

The detection of highly-enriched uranium is significantly more challenging because its passive emissions are essentially limited to gamma rays, which can be easily shielded by a single type of material. For this reason, active-interrogation techniques are being developed in the NERS department and elsewhere. Within NERS, the Neutron Science Laboratory (NSL) houses two neutron generators capable of producing intense fields of accelerator-based fast neutrons. One of the neutron generators housed at the NSL is a 14-MeV neutron generator, which produces neutrons by accelerating deuterium (D) ions into a tritium (T) bearing target with intensity up to 108 neutrons per second with a fast and highly flexible pulsing capability. This makes it ideal for active-interrogation studies in which time correlations of radiation emissions are investigated. In the new Nuclear Engineering Laboratory (NEL), a 9-MeV Varian linear accelerator is being commissioned to provide new opportunities for growth in the area of active interrogation using bremsstrahlung photons to induce photofission in nuclear materials.

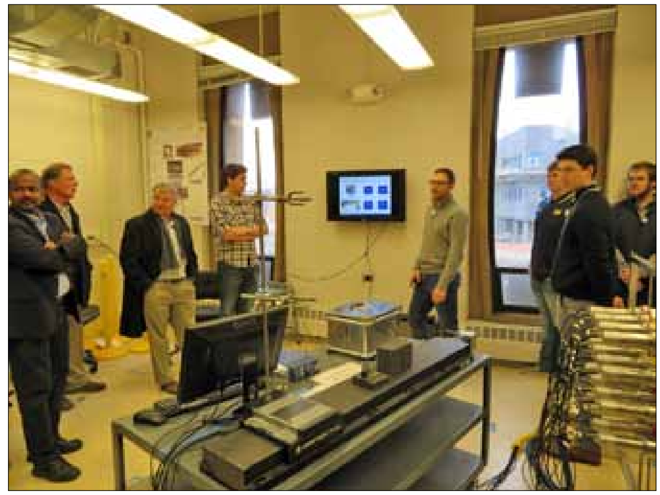
New active-interrogation systems based on transportable accelerators (superconducting cyclotrons) lie at the forefront of technology for homeland security and medical applications. These machines can accelerate protons or deuterons at energies on the order of 10 MeV and generate intense beams of neutrons and gamma rays by employing appropriate targets (boron, nitrogen, etc.). These beams can be used for penetrating radiography or to induce fission, increasing the magnitude of characteristic signatures of SNM.

Bright, quasi-monoenergetic and continuously tunable sources of photons in the MeV range can be produced in laser interactions with relativistic electrons. In the recent implementations, both the laser and the electron beam are produced with the same laser system. These sources, once ruggedized and miniaturized, have the potential to revolutionize active-interrogation systems based on photofission and nuclear resonance fluorescence.

New nuclear safeguards and treaty verification techniques have been in high demand recently, particularly due to the shortage of He-3 gas, which was a main component of detection systems used



Advanced radiation detector development



Demonstrating radiation detectors

in the past 40 years. There is also an accompanying strong interest in improving those techniques by employing advanced detectors, systems and new measurement methodologies, for example fast neutron detectors, room-temperature high-resolution gamma spectrometers and digital data acquisition and processing systems. Measurements that employ spectroscopy of laser-produced plasma may offer rapid elemental and isotopic discrimination at standoff as well as in some challenging environments, such as those in which intense mixed radiation fields are present. These techniques are required for verification of weapons dismantlement and of uranium and plutonium compounds at all stages of the fuel cycle. Facilities that require these measurement systems include nuclear fuel fabrication and reprocessing plants. Nuclear detection schemes developed in NERS will help bring the accuracies of these non-destructive analysis techniques to the required 5% or better.

Nuclear forensics is another area of growth for the NERS department. Commissioning a new neutron DT generator with flexible, high-contrast pulse format allows the development of high-fidelity neutron activation analysis techniques in which the observation of radiation signatures unique to the sample composition can be realized in close time proximity to irradiation. High-power lasers are also under investigation as compact high flux sources of energetic neutron and proton beams for these applications and can also be used to produce luminous plasmas by laser ablation. Such plasmas can be spectrally analyzed to determine the sample composition in techniques such as laser-induced breakdown spectroscopy.

Another area of research in nuclear security includes methods to detect and disable improvised explosive devices (IEDs), one of the most significant and deadly threats faced by armed service personnel and innocent civilians in current conflicts. IEDs are responsible for nearly half of the hostile fire deaths in Iraq and Afghanistan. NERS faculty have recently investigated the use of high-power microwaves (HPM) to significantly reduce the IED threat by remotely disabling detonation triggers (thermally or electrically). Compact HPM systems under study employ 100 MW single-sources as well as power-combining of several medium-power (100 kW) sources. Various methods of phase locking of multiple oscillators and power combining are of fundamental interest for the next ten years. The NERS department is the world leader in developing such HPM sources, using multi-kA, mega-volt pulsed power systems.

The Department is making a significant effort to strengthen the interface between technology and policy in the area of nuclear security, safeguards and defense. To that end, the Consortium for Verification Technology has established a close connection between NERS research and some of the key academic and government leaders in the area of nuclear security policy. This is clearly an opportunity for significant growth in both research and education in NERS.

Environment and Health Futures Thrust Area

Nuclear engineering has amazingly broad applications, particularly in the environmental and health areas. This section will deal with these in four parts. The first two parts deal with two well-established fields, medical physics and health physics, that involve nuclear technology and are well defined by curricula offered through both nuclear engineering and other departments. Both have distinct accreditation mechanisms and non-engineering board certification for practitioners. The third part outlines the newly emerging field of Plasma Medicine. The final part addresses less circumscribed but opportunity-laden applications involving nuclear engineering and the environment and health.

Medical Physics

Since the NERS department's 2013 strategic plan, substantial changes have taken place in both the overall profession of medical physics and academic opportunities for graduate students at the University of Michigan. A postdoctoral certificate program, jointly administered by the Department of Radiation Oncology in the Medical School and the NERS department, was created and accredited by CAMPEP. This allows students who already have a doctorate to achieve the necessary credential to enter a clinical residency in medical physics, the next step toward board certification as a clinical medical physicist. Processes are underway for CAMPEP accreditation of NERS master's and doctoral sub-plans in medical physics, which would extend this opportunity to graduate students. Such accreditation was unanimously approved by the NERS faculty.

Health Physics

Radiation safety, or health physics, is a topic included within major nuclear engineering departments nationwide as well as within stand-alone, separately accredited undergraduate and graduate programs. Professional certifications exist for health physics but do not require graduation from accredited programs and are not required for practice. Health physics is a broad, distinct subfield that focuses on the protection of people and the environment from radiation. Overall topics addressed within the field include operational practices, public communications, environmental transport of radionuclides, interactions of radionuclides within the biosphere, prospective and retrospective internal and external dose assessment for both people and animals, and radiation health effects. Because of the evaluation of long-term health impacts and the importance of considering dose to workers and environmental contaminations as a result of operations, knowledge of health physics for nuclear engineers involved in designing and operating nuclear power plants is critical. The Fukushima Daiichi nuclear power plant accident and the significant potential for a radiological terrorist event both shine strong light on the importance of health physics. Funding for decommissioning and other work are opening up new opportunities in this field.

Plasma Science Solutions for the Environment and Health Care

Low temperature, atmospheric pressure plasmas hold great promise for environmental mitigation as well as for the field of health care. Such nonequilibrium discharges produce copious amounts of very reactive radicals. Radicals and other products are produced, collectively known as advanced oxidation processes, that chemically activate gaseous or liquid environs. There are three key areas where such enhanced reactivity can make a major impact: 1) water purification, 2) toxic gas and contaminated soil cleanup and 3) the treatment of disease. Currently, conventional water treatment plants address particulates and bacteria and viruses. Volatile organic contaminants, pesticides, herbicides and pharmaceuticals represent a new and emerging threat to our fresh water supplies. Advanced solutions will be required to remove these contaminants. Plasma injected in water has the capacity to mineralize these contaminants, reducing them to carbon dioxide and water. The same goals can be achieved for the treatment of manufacturing exhaust plumes. In the gaseous state, plasma renders the gas reactive, so that in the presence of molecules such as oxygen, such plasma has the capacity to either consume the toxins or render them harmless. Finally, it is now well documented that plasmas have curative effects on human tissue. Indeed, wound healing has been demonstrated, particularly in cases of chronic wounds (e.g. in diabetic patients), although the curative properties are not well understood. Plasma-medicine, as this growing field is called, can potentially revolutionize the way medical procedures are carried out. It is believed that plasma directly produces active chemicals that would be produced by the body, but much more slowly, in response to disease or a wound. All in all, nonthermal plasmas likely will play a key role in environmental mitigation and healthcare. A serious research effort in these emerging areas is key to making advances in understanding and application—as well as ultimately maturing these fields.

Cross-cutting Environmental and Health Issues

In addition to the above, nuclear analytical methods, such as DNA analysis and use of tracer methods, and radiation processing — for example, radiation treatment of materials for implants — are essential for biomedical research and bioengineering. These areas continue to be relevant to new approaches and methodologies as those fields continue to evolve. Traditional radiation sterilization of food and water, in addition to plasma methods mentioned above, present nuclear engineering challenges of global significance during times of resource constraints, expanding world population and global warming. Continuing problems that merit politically and technically viable solutions include: high level waste (used nuclear fuel) disposal, remediation of radionuclide-contaminated areas from legacy atomic weapons production facilities and nuclear power plant accidents (Fukushima) and environmental issues during the front end of the nuclear fuel cycle. These are also problems that cross the traditional boundaries of the NERS department's areas of excellence.

Educating individuals with the breadth of skills and knowledge across what traditionally have been the measurements, health physics/radiological engineering, materials, and plasmas areas of the department would not only benefit those students by widening their scope of employment opportunities, but also strongly benefit society by providing a cadre of nuclear scientists with incredible depth and breadth. Doing whatever is possible to bridge the traditional boundaries of the NERS department to address cross-cutting environmental and health issues is likely also to lead to research funding in emerging areas.

Enabling Scientific Discovery

There are two complementary components of this thrust area:

a) Modeling and simulation

b) Fundamental nuclear, atomic and plasma theory and data measurements.

These research areas are complementary because computer codes can only produce meaningful predictions when accurate cross sections and atomic data are available.

Modeling and Simulation

For the past two decades, simulation has been described as the "third leg of science" that complements traditional theory and experiment. The Laboratory for Scientific Computation was created in the late 1980s by William Martin to satisfy the growing need for computational scientists who are expert in their scientific domains but rely on modeling and simulation to conduct their research. This includes researchers who develop the tools and algorithms that enable computation and simulation, as well as the scientists who use these tools. Scientific computation, here called "computational science," has pervaded nearly all disciplines of research and now includes physics, mathematics, engineering, statistics, social science and others.

With the advent of multiphysics/multiscale simulation, such as coupled neutronic/thermal-hydraulic (TH)/materials/structural analyses for nuclear reactors and integration with experiments, modeling and simulation has enabled interdisciplinary research among several of the primary research areas of NERS, including:

• Fission

The Consortium for Advanced Simulation of Light water reactors (CASL) Energy Innovation Hub, in which NERS participates, is one example of the investment being made by the federal government in modeling and simulation of multi-physical phenomena. A related issue in reactor multiphysics is that practical simulation of thermal hydraulic phenomena involves the use of "closure relations" that only approximately describe complex phenomena, such as turbulence. The increase in available computational resources has led to greater interest in high-resolution first-principle computational fluid dynamics (CFD) models, which can be used to inform development of more accurate closure relations. Several government agencies, including the U.S. Department of Energy (DOE), National Nuclear Security Administration, Department of Defense, National Science Foundation, Department of Homeland Security, and the National Aeronautics and Space Administration (NASA), are all investing heavily in modeling and simulation efforts of these types. These should be growth areas for years to come.

• Fusion and Plasma (high energy density plasma physics)

The development of fusion energy involves coupling of extensive plasma fluid (MHD) and kinetic simulations with experiments both in inertial confinement and magnetic confinement. The development of compact plasma-based accelerators and radiation sources also involves extensive kinetic modeling and is one of the drivers of the use of advanced particle-in-cell techniques. In addition, the Stockpile Stewardship Program (SSP) of the DOE is predicated on the fact that since nuclear weapons cannot be tested, the safety and reliability of the U.S. nuclear stockpile is based on modeling and simulation, augmented by experimental programs that cannot include nuclear detonation.

• Nuclear Measurements (detection of special nuclear materials)

Another example is the use of high-performance computing, combined with measurements, to accurately

CASL Titan Supercomputer at ORNL

and rapidly solve nonproliferation and homeland security problems, e.g. the detection of special nuclear material (SNM). The Consortium for Verification Technology (CVT) and the Center for Nonproliferation Enabling Capabilities (CNEC), of which UM is a member, study problems of this nature, with CVT more focused on the physics, data and measurements, and the CNEC more focused on computation.

• Nuclear Materials

Another example is the development of high-fidelity methods to calculate ion beam "simulations" of neutron irradiation. This work is now being funded (in NERS) by the Nuclear Energy University Program. A goal of this project is to predict the irradiated microstructure and corresponding mechanical behavior of materials under long-term irradiation, using improved mathematical and computational models validated against both ion and reactor irradiations and verified against ion irradiations. This will yield an enhanced capability for simulating the behavior of materials in reactor environments.

Overall, modeling and simulation depend on the combination of experimental data, theory and calculations to produce realistic results. In all cases, the experimental data and the calculations are inexact, due to (i) uncertainties in the data and (ii) truncation or statistical errors in the simulations. It has become important to validate the computational models and to quantify the uncertainty in the predicted result. This area, known as verification, validation, and uncertainty quantification (V&V and UQ or simply VUQ), has been another rapidly growing field of computational science. The largest investment in VUQ is probably by DOE/NNSA for the SSP, but CASL also spends a considerable portion of its budget (about 20%) on VUQ. Since VUQ can provide information for decision-makers (e.g. quantifying the probability that a given system will fail under a specified set of circumstances), it is a field of growing interest to many federal agencies.

There is a dearth of experimental data for validation of many of the simulation models used by CASL. For example, multiphysics modeling of nuclear reactor phenomena has very little measured data that can be compared to simulation results. Multiphysics experiments that generate measured data for comparison to predicted results would be welcomed by funding agencies. The CASL researchers would welcome this and would be willing to consider funding such activities.

Fundamental Nuclear and Atomic Data Measurements

The NERS department has a long-established reputation for measurements of fundamental nuclear and atomic data, building on the pioneering neutron cross-section measurements of Glenn Knoll. The current portfolio of these activities by NERS faculty includes:

- Fundamental nuclear and atomic data measurements
- Astrophysical applications of gamma ray cameras
- Fundamental studies of the interaction of ultra-high intensity laser pulses with matter
- Calculations and measurements of electrical contact resistance, electrothermal instability and magneto Rayleigh Taylor instability.

Several of these research activities are discussed below as they relate to the future of the NERS department.

Nuclear fission is a complex reaction that emits multiple neutrons and gamma rays with unique energy, angle and multiplicity distributions. Basic physics data describing these emissions are crucial for many applications. Specifically, the correlations among number, energy and directional distributions of these particles are not well known, even for very important isotopes such as U-235 and Pu-239. Improving the knowledge of these distributions is crucial for many applications, including those involving simulation codes needed to evaluate the performance of existing measurement systems for special nuclear materials and to develop new, innovative ones.

Fast neutron generator

Recent developments in digital data acquisition systems and detection materials provide opportunities for new measurements of the emissions from nuclear fission. These measurements will significantly improve the accuracy of correlated neutron and photon data. It is expected that these improvements will benefit the national and international user community in both Monte Carlo and deterministic codes. To this end, Sara Pozzi's group in NERS has performed and is planning new experiments at the Los Alamos Neutron Science Center (LANSCE) with the objective of measuring the energy-angle correlations of neutrons emitted from both spontaneous and induced fission of isotopes of interest. This activity is funded by the Consortium for Verification Technology, which has a thrust area in Fundamental Data and Techniques. LANSCE provides the world's best facility for the measurement of neutron-induced fission, and this collaboration will improve the quality of the nuclear data available for many applications.

Scientists in NASA communities are interested in three-dimensional position-sensitive CdZnTe semiconductor gamma-ray imaging spectrometer technology, invented in NERS, for gamma-ray astrophysics and planetary science applications. Astrophysicists are interested in 3D CdZnTe technology for future astrophysics satellite missions to study the nuclear synthesis process in stars. Scientists in the planetary science community are interested in this technology to measure elemental compositions and search for water in planetary bodies, such as on Mars and the moon. Zhong He's group has conducted joint experiments at the NASA Goddard Space Flight Center. This experiment used a pulsed neutron generator to activate different rock samples and to image and identify gamma-ray emissions from various rocks and metal samples using UM's Polaris CdZnTe gamma-ray imaging spectrometer system. The goal of this experiment was to demonstrate unique capabilities of CdZnTe imaging spectrometers for determining elemental compositions in future planetary science missions.

Another example of advancing fundamental science to enable scientific discovery is the joint research effort and experiments in collaboration with the physics group led by Professor Kai Zuber of Germany. One experiment was conducted in Gran Sasso underground laboratory in Italy to demonstrate unique background rejection capability of 3D CdZnTe detectors for extremely low radiation background measurements. The goal of this research was to search for neutrino-less double-beta decays and measurements on specific decay cross-sections of cadmium isotopes (one element in CdZnTe) that can confirm or verify proposed theories and hypotheses and to determine some fundamental constants of interest to the nuclear physics community.

Other NERS facilities are well suited to measurements of fundamental nuclear data, including the Neutron Science Laboratory, which contains a deuterium accelerator source of 2.45 MeV neutrons, and the Detection for Nuclear Nonproliferation Laboratory, which will house a 9-MeV electron linear accelerator.

In the plasma science area, ultrafast, TW-PW lasers make it possible to study the fundamental science of the interaction of ultra-high intensity lasers with matter including relativistic effects. The laser systems in NERS generate femtosecond duration electron beams up to 1 GeV as well as neutron, gamma ray and positron beams. Understanding the physics is required

Student activities

before the radiation sources generated by these lasers can be directly applied to medicine or other fields. However there are also now uses of the radiation sources produced by laser-driven accelerators, which can be applied for scientific measurements of warm dense matter (using x-ray absorption spectroscopy), x-ray imaging of shocks with sub-picosecond temporal resolution and electron diffraction measurements of solid-state materials.

Fundamental theory, simulations and experiments of the magneto-Rayleigh Taylor instability on the unique MAIZE facility provide insights into astrophysics phenomena associated with supernovae and magnetized high energy density plasmas as well as advanced fusion concepts.

Meeting the Challenges of the Future

For over seven decades the Michigan Memorial Phoenix Project and the Department of Nuclear Engineering and Radiological Sciences have been regarded as global leaders in nuclear research and education. Today they continue to provide important contributions in contemporary areas such as:

- preventing the proliferation of nuclear weapons technology
- developing new methods of radiation in diagnosing and treating disease
- developing advanced forms of nuclear energy, such as next generation fission reactors and thermonuclear fusion reactors and, of course,
- helping train future generations of nuclear

Student activities

Student activities

scientists and engineers to serve the nation and the world.

Although nuclear power faces serious challenges today in terms of public perceptions, particularly in the wake of the tsunami damage to the Fukushima Daiichi power plants and the rapidly changing financial environment driven by development of shale gas hydraulic fracturing, it nevertheless provides 70% of the carbon-free electricity generated in the United States and is projected to double in capacity at the global level to over 500 GW by 2030. This is particularly important in view of the belief by over 90% of the scientific community that global climate change driven by human activities, such as the burning of fossil fuels, is not only a certainty but likely the greatest challenge facing our world. This demands mitigation through development and deployment of carbon-free energy sources, such as nuclear power and renewable energy technologies (e.g. wind and solar power).

The rapid increase in biomedical knowledge at the cellular and molecular level has provided new applications of nuclear technologies for both detecting and treating disease.

So too, our world faces major challenges today from the proliferation of nuclear weapons technology. The international agreements that restrained such proliferation in the past are increasingly bypassed by emerging nations, requiring new methods for monitoring and new political approaches for constraining both the development and threat of this terrifying technology.

In fact, in much the same way nuclear war was the great challenge facing humankind when the University of Michigan launched the Michigan Memorial Phoenix Project, developing sustainable and environmentally benign energy sources is the great challenge today, deserving once again of an extraordinary leadership effort on the part of the University of Michigan.

The University of Michigan Department of Nuclear Engineering and Radiological Sciences


Michael Atzmon


Alex Bielajew


Thomas Downar


James Duderstadt


John Foster


Fei Gao

Today's NERS Faculty


Ronald Gilgenbach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James Holloway


Igor Jovanovic


Kimberlee Kearfott

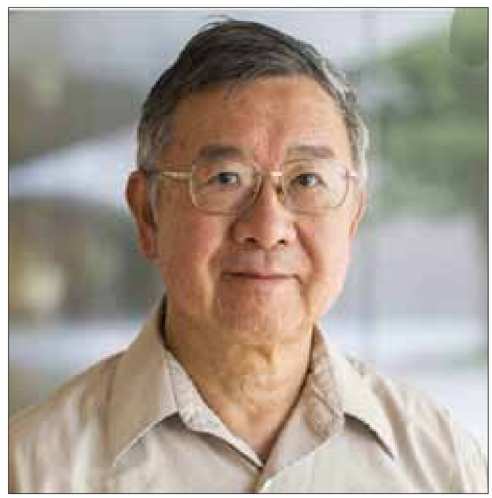

Brian Kiedrowski

Today's NERS Faculty

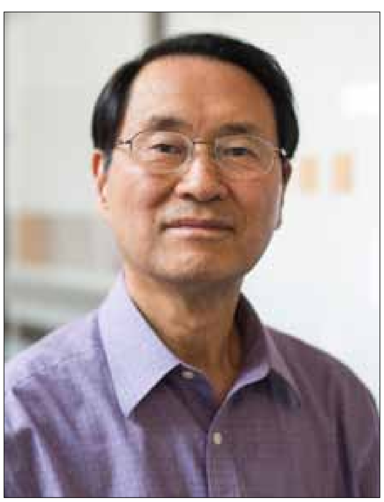
Karl Krushelnick

Mark Kushner

Edward Larsen



Yue Ying Lau



John Lee

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Today's NERS Faculty


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Sara Pozzi


Xiaodong Sun


Alex Thomas

Today’s NERS Faculty

Lu-Min Wang

Gary Was

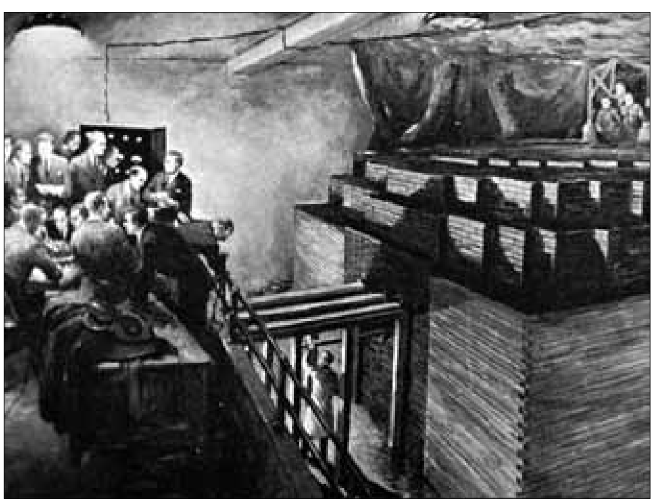
David Wehe

Won Sik Yang

Appendix A
The History of the U.S. Nuclear Power Program

E. O. Lawrence, Enrico Fermi, Leo Szilard

CP-1 Nuclear Reactor (U. Chicago)



First Nuclear Chain Reaction

Oak Ridge Laboratory

History of U.S. Nuclear Program

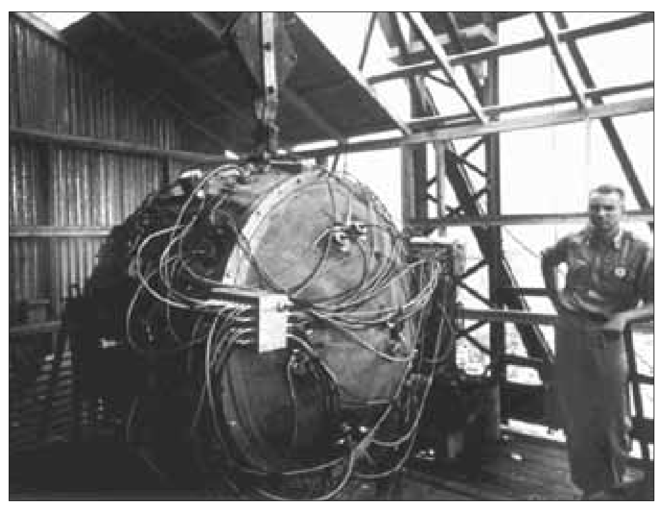
Hanford Reactors

Hanford Plutonium Plant

Hanford Community

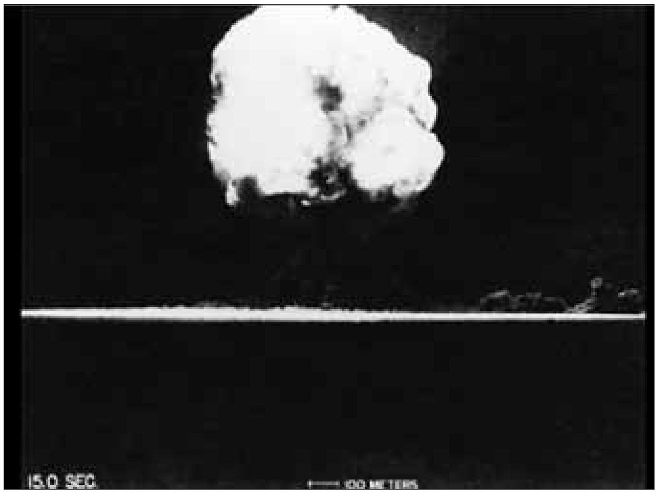
Los Alamos Boys School

Los Alamos Laboratory

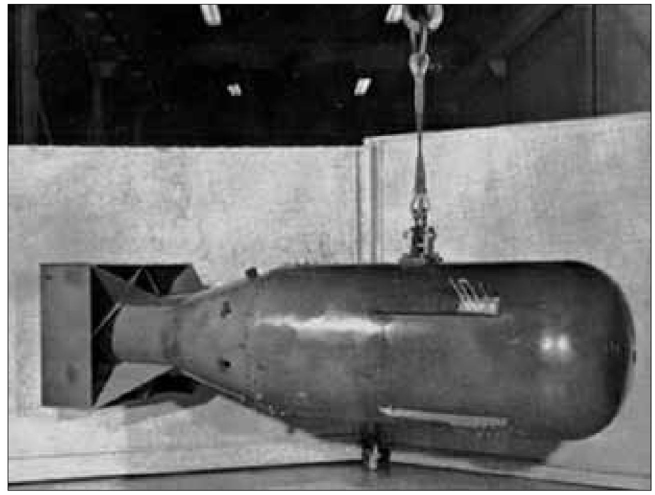


"The Gadget" (plutonium implosion bomb)

History of U.S. Nuclear Program



First Nuclear Explosion (Trinity)



Gun-Type uranium fission bomb

Bomber taking off for Hiroshima

Hiroshima nuclear explosion

Hiroshima damage

President Truman signs the Atomic Energy Act

History of U.S. Nuclear Program

Atomic Energy Commission Laboratories

Oak Ridge National Laboratory

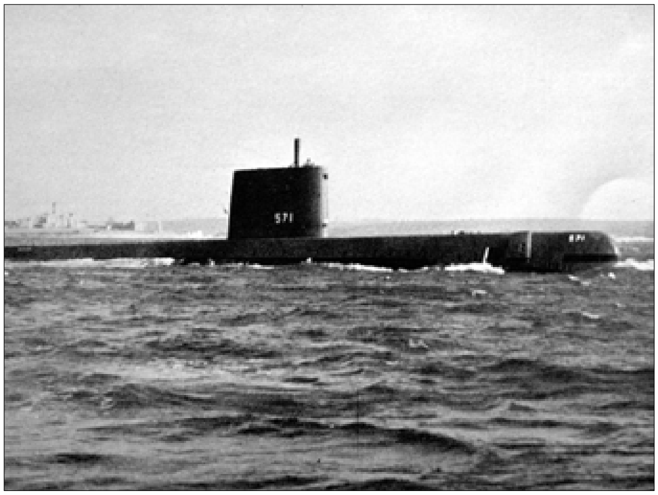
Portsmouth uranium processing plant

Los Alamos National Laboratory

Lawrence Livermore National Laboratory

Experimental Breeder Reactor (Idaho)

History of U.S. Nuclear Program



Nautilas nuclear submarine

Shippingport nuclear plant

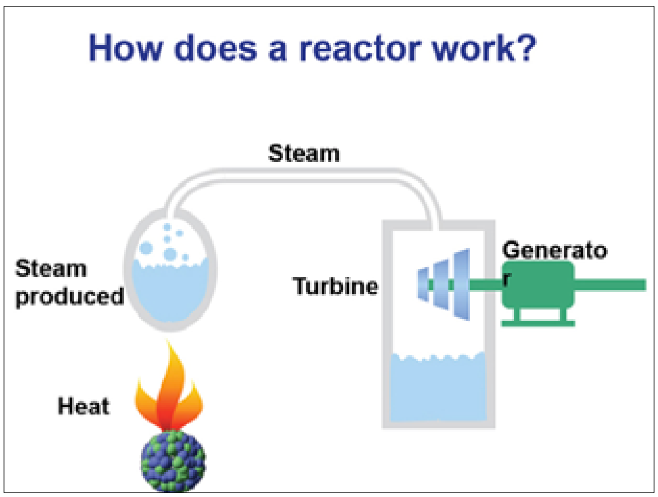
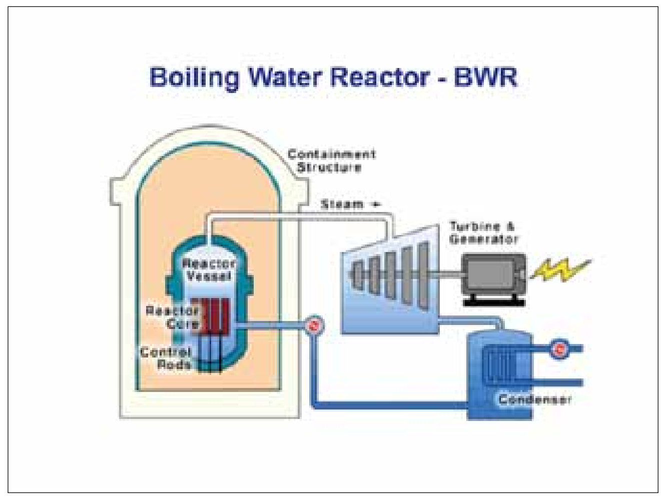
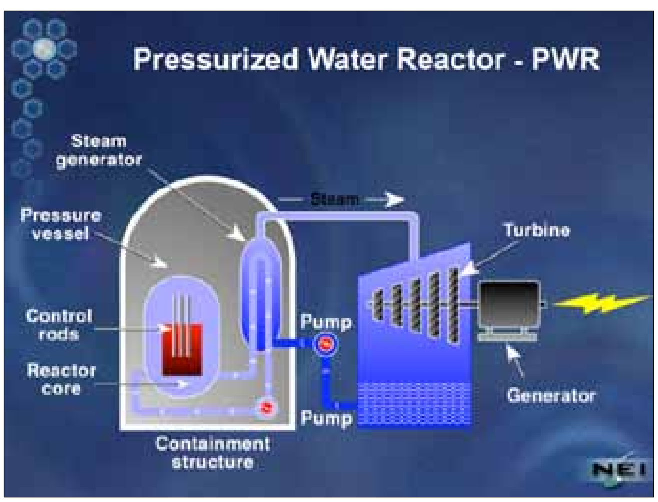


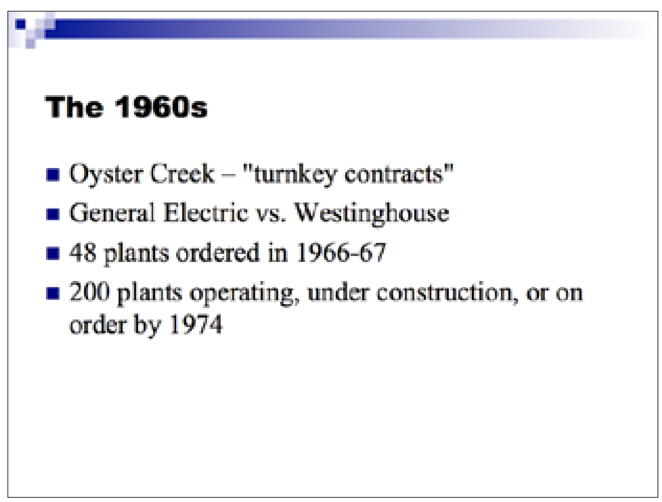
Diagram of Nuclear Power Production



Boiling Water Reactor



Pressurized Water Reactor



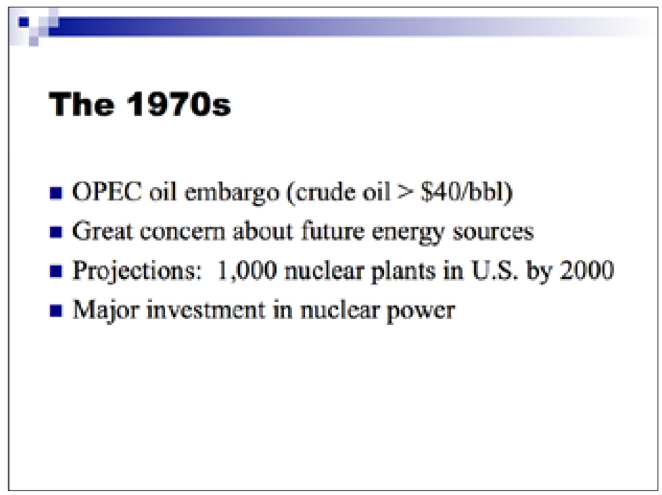
Early United States Nuclear Power Program

History of U.S. Nuclear Program

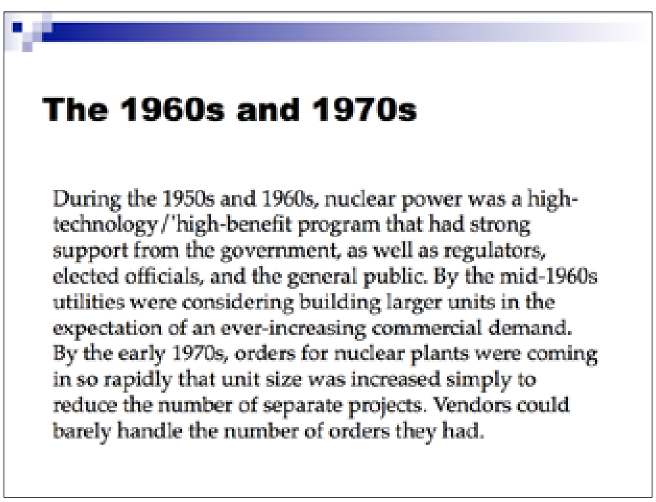
Palisades Nuclear Plant (Michigan)

Fermi II Nuclear Power Plant (Michigan)

Davis Besse nuclear power plant (Ohio)



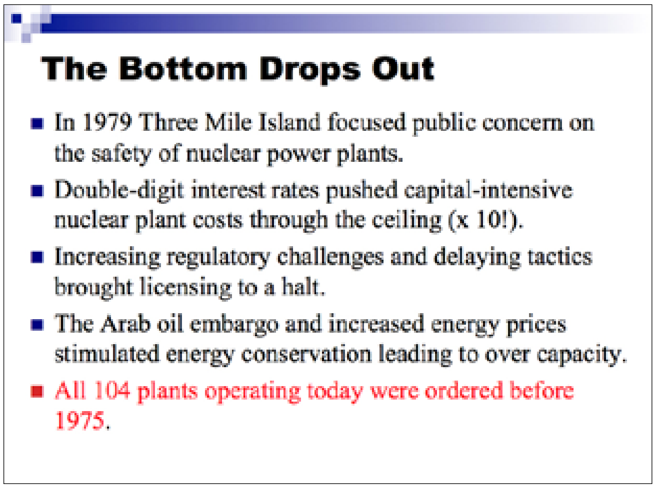
1970s Nuclear Power Program



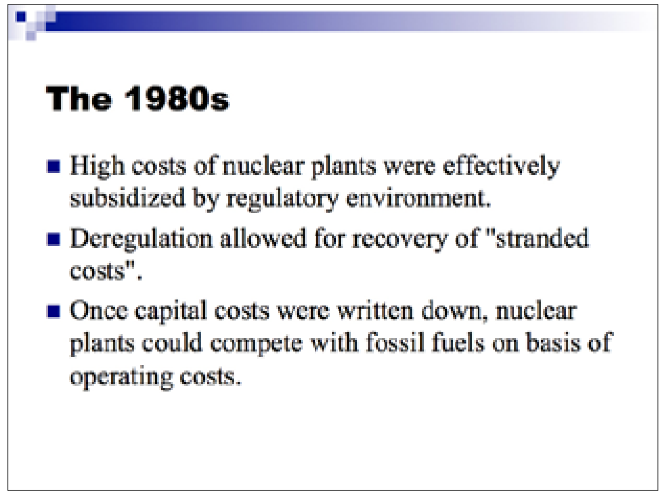
Nuclear Power Expansion

Three Mile Island

History of U.S. Nuclear Program



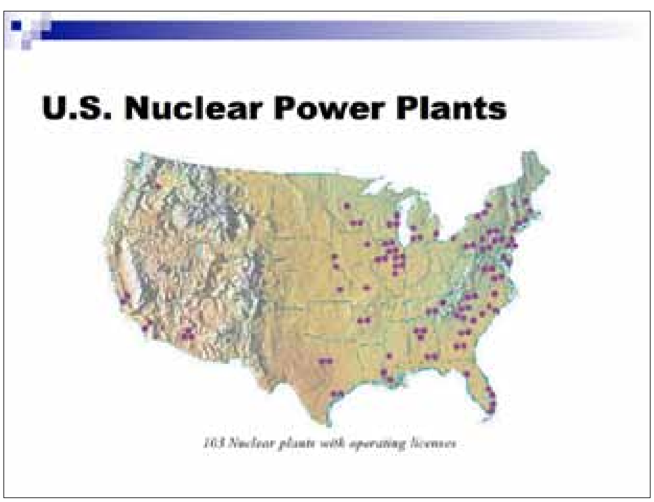
The decline of nuclear plant construction



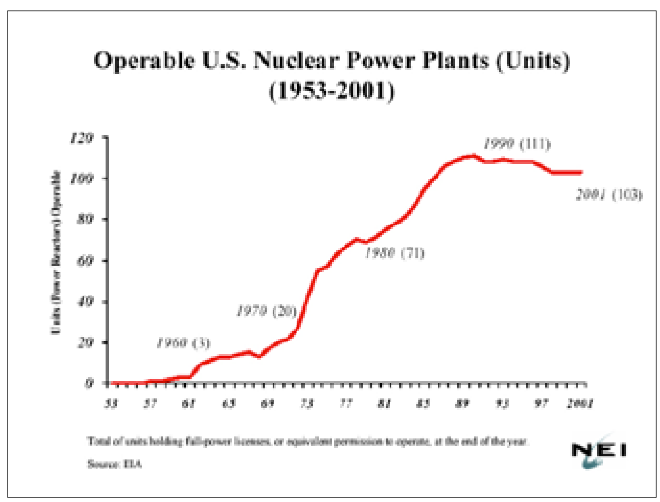
1980s nuclear program

USSR Chernobyl Nuclear Plant

Chernobyl Nuclear Plant accident

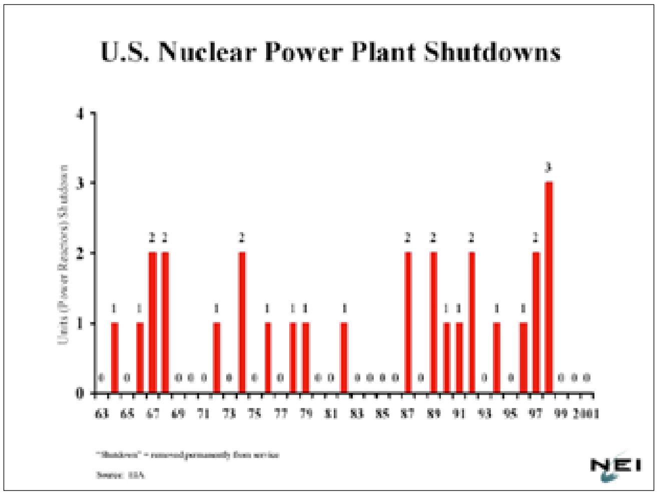


2000s Nuclear Power



Leveling Off of U.S. Nuclear Plant Growth

History of U.S. Nuclear Program



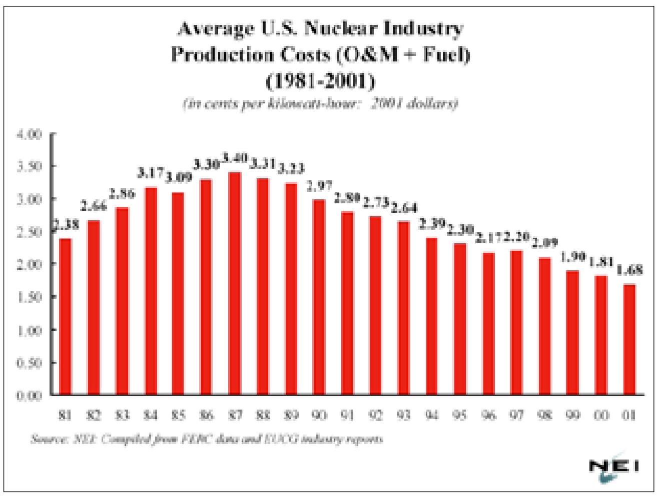
U.S. Nuclear Plant Decommissioning

Deregulation

By the late 1980s, even though nuclear plants were not competitive with fossil fuel plants, they were still protected by a regulatory environment that allowed utilities to recover capital costs. That equation began to change by the mid 1990s when states began to reexamine the issue of retail electricity competition. In states with nuclear power plants, the most contentious issues in the deregulation debate have come down to how utilities can recover the stranded costs embedded in these plants.

Settlements allowing for recovery of stranded costs over a period of years enabled utilities to write down the high capital costs related to the construction of nuclear plants. Once the plants were written down, nuclear plants could compete strictly on the basis of operating costs, which gave plant operators a very strong incentive to control operating and maintenance costs.

Deregulation of Electric Power Market

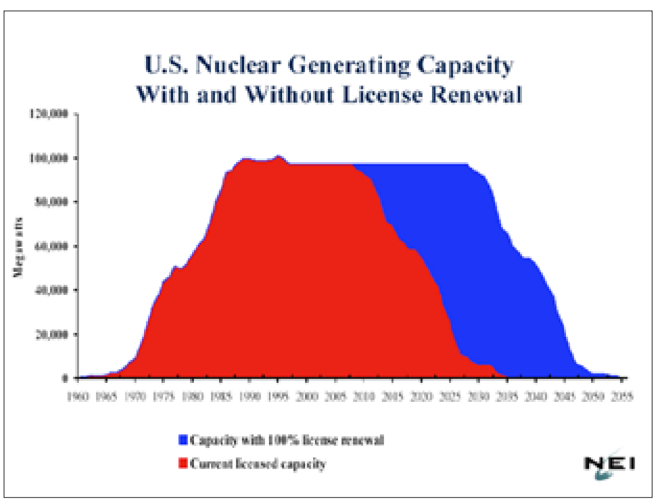


Nuclear Plant Electricity Costs

The 1990s

- Recovery of stranded costs
- Improvement in capacity factors (60% to 90%)
- Consolidation of nuclear plant operators
- By 1999, nuclear plant operating costs had dropped below those of coal-fired plants (2 cents per kwh)

1990s Nuclear Industry



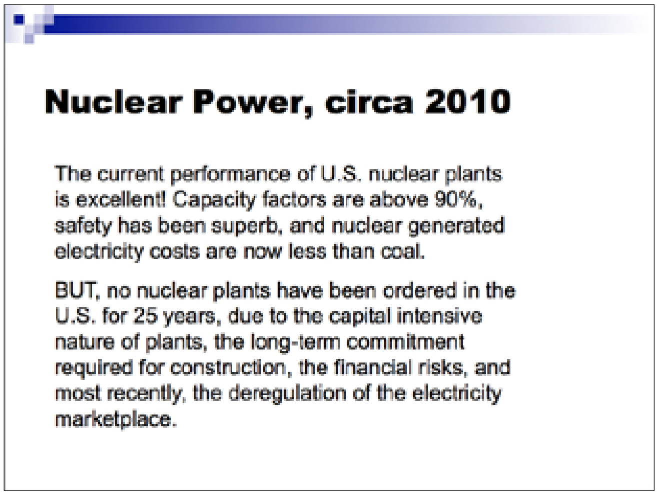
Relicensing of Nuclear Plants

Energy Policy Act of 2005

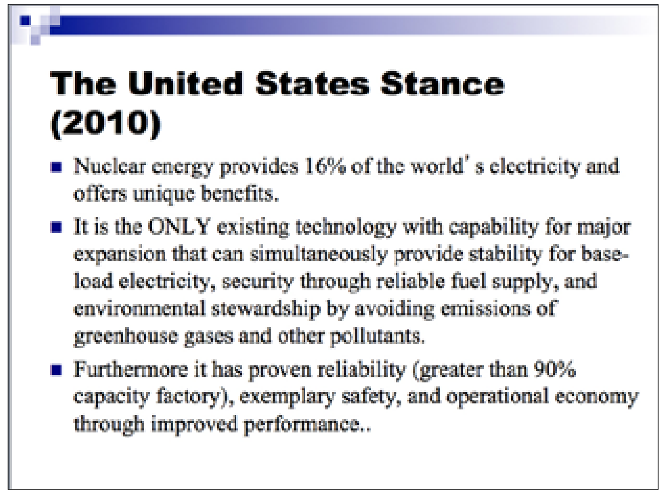
- Price Anderson Act is extended to 2025 ($10 billion indemnity against liability)
- $100 million authorized to demonstrate hydrogen production at existing plants
- Allows DOE to provide financial backup for 6 reactors (up to 3 designs) for delays in NRC licensing up to $500 million.
- Authorizes $1.25 billion for next generation design prototype to produce electricity and hydrogen (at INL)

Energy Policy Act of 2005

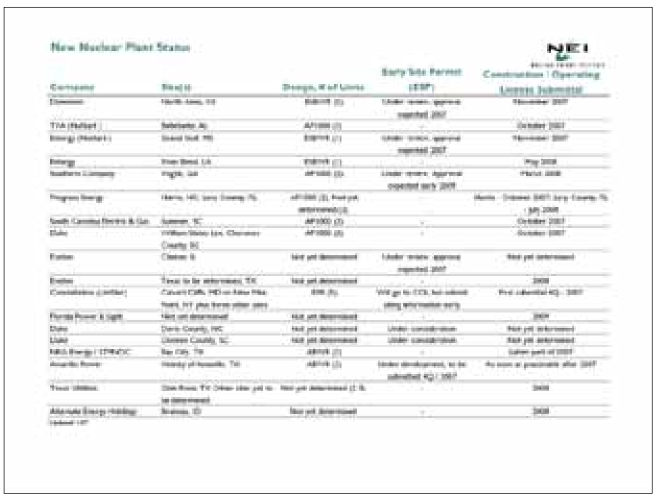
History of U.S. Nuclear Program



2010 Nuclear Power Industry

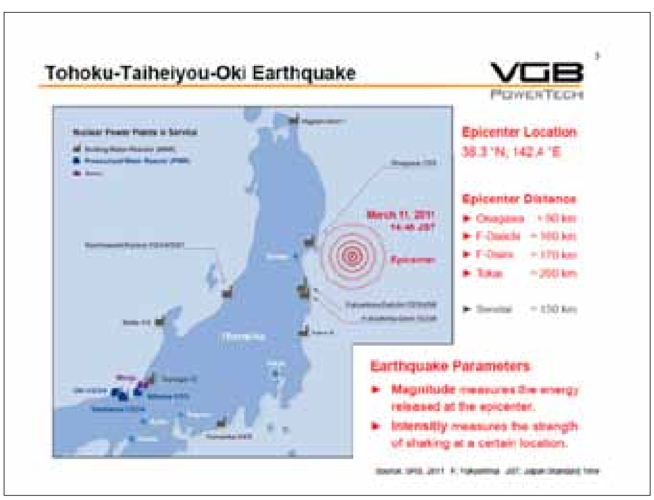


U.S. Nuclear Power



Possible "nuclear renaissance"

Japan Fukushima Daiiachi Nuclear Plant



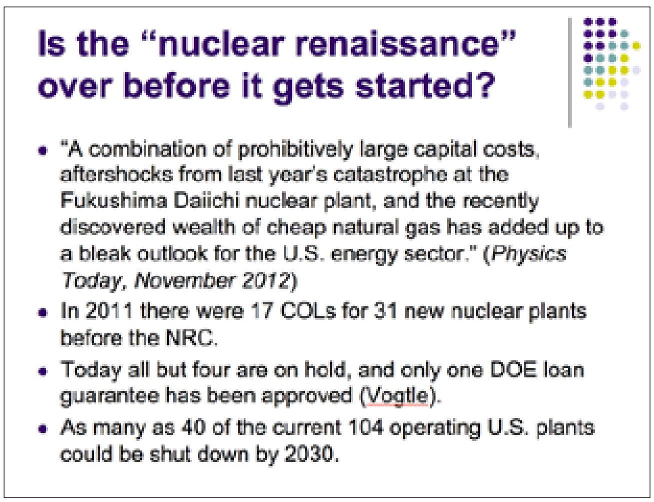
Japanese Tsunami

Tsunami strikes Japanese nuclear plant

History of U.S. Nuclear Program

Tsunami destroys emergency cooling system

Fukushima plant is destroyed



The U.S. Nuclear Renaissance never happens

Model of Chinese nuclear plant

Chinese nuclear plant Ccnstruction

United Arab Emirates nuclear plant odel

History of U.S. Nuclear Program

Appendix B

The Future of the U.S. Nuclear Power Program

So where is the U.S. nuclear power industry today?

First, the good news: Nuclear power remains the nation's most reliable clean energy source, supplying not only 20% of our electricity but 64% of our clean power. Our nation's nuclear plants generate three times more electricity than hydropower and five times more than wind energy. One nuclear plant with two units avoids the emission of more carbon than all the U.S. solar energy capacity in 2014. Indeed, the amount of carbon dioxide emissions avoided by nuclear energy is equal to that produced by all the passenger cars in the United States.

Today's nuclear plants are characterized by extraordinary reliability and efficiency, operating at over 90% capacity factors. Nuclear plants provide stability to the electrical grid with constant and reliable output. They are available at nearly all times and in all weather conditions.

Today's 100 operating nuclear plants generate $40 to $50 billion each year in electricity sales. As a consequence of their reliability and efficiency, the nation's electrical utilities have filed for license renewals for over 70 of these nuclear plants, to enable them to operate for 20 more years after their initial 40-year operating license. Indeed, significant efforts are underway to develop the capacity to extend plants for yet another 20 years, achieving "life after 60."

Now for the bad news: The U.S. nuclear fleet is aging. There is great concern about today's nuclear plants reaching their end of life…or being shut down for economic reasons. The average nuclear plant is 35 years old, nearly obsolete by modern design standards, and close to the end of its operating license. Within the past several years, six states have shut down nuclear plants, and many other plants are at risk of premature retirement. Over 30 of the nation's nuclear plants will reach 60 years of operation in the 2030s. Of course, some plants will seek a second license renewal, but many will have to be replaced. Seven plants have shut down since 2013. More are on the block.

Even if today's reactors can operate to 80 years, we will need 18 GWe of new nuclear capacity by 2030 and 23 GWe by 2035 to maintain a 20% share of electrical supply. Yet of the 59 new nuclear plants under construction worldwide, only four are in the United States, about enough to compensate for older reactors that are shutting down. The Tennessee Valley Authority's Watts Bar 2 is the 100th operative nuclear power plant in the United States, the country with the most nuclear-powered states in the world. Watts Bar 2 is also the first nuclear power plant to be built in this country in two decades. There are only two nuclear plants under construction in the United States today, compared to 21 in China and a growing business selling reactors to other countries.

Challenges

To some degree, the decline in nuclear power is driven by public concern. Just about every time nuclear power seems ready for a surge, something happens to undermine public confidence. To be sure, events such as those at Three Mile Island, Chernobyl and Fukushima Daiichi have raised serious concerns. Ongoing concerns about costs (with today's nuclear plants costing over $10 billion and requiring a decade or more to build), radioactive waste disposal, burdensome regulation and negative publicity (e.g. movies such as "The China Syndrome") have stalled nuclear power development.

But perhaps most serious has been the changing technologies and economics in the energy market.

A decade ago, people were talking about a nuclear renaissance and suggesting fossil fuels were approaching Hubbert's Peak, with fossil fuel reserves declining rapidly thereafter. Then shale fracturing technology ("fracking") began to unleash vast reserves of low-cost shale gas (with only 50% of the carbon emissions of coal). In past decade, U.S. natural gas production has increased by 50% and, ironically, emits half as much carbon dioxide as coal, as it replaces coal for electricity production. But it is still a carbon-emitting technology and contributes to climate change.

Finally, baseload nuclear plants, highly profitable in the earlier days of regulated electrical markets and vertically-integrated utilities, found it difficult to compete with the more flexible character of gas-generated electricity and distributed generation, especially given the immense size (two to three times the size of coal plants), costs and construction time required for today's nuclear plants — $10 billion and 10 years to develop and build — before they start making money. They are not "manufactured" but rather built, one by one, unlike the standardized and modular designs used in China and France.

Their high cost makes them a colossal financial risk, a "bet the whole company" proposition. The only place where they are economically viable is in regulated electrical markets and vertically-integrated utilities (controlling generation, transmission, and distribution and able to set rates that will earn back investments). Unless natural gas prices go up, new nuclear plants will only be economically feasible in states with electric utility monopolies (regulated), such as Georgia, South Carolina and North Carolina.

We also are beginning to see dramatic improvements in the costs of wind and solar power. Compared to these renewable energy sources, nuclear power does not play on a level playing field. Unlike wind and solar energy, which receive hefty federal and state subsidies, nuclear providers have not seen the same support — despite providing consistent, large-scale and reliable carbon-free energy. Of course, along with cost, factors such as production of carbon-free electricity, reliability, grid stability and diversity of fuel supply should influence U.S. energy policy. But energy sources do not consistently receive credit for helping attain these goals; likewise, they are not consistently penalized if they fail to do so. Only recently have states such as New York begun to transition from "renewable" policies to "clean energy policies" by including nuclear power in subsidies, using a "clean energy standard" to keep several existing nuclear plants operating.

Electricity Generating Costs (2017)

Nuclear Plants: $99.70 per MWH
Gas Plants: $56.40
Wind: $50.90 with tax credits
Solar: $58.20 with tax credits

A Broader View

Is the future of nuclear power development in the United States slow, over-budget, and economically untenable? The U.S. Department of Energy (DOE) estimates that U.S. electricity demand will rise 28% by 2040. We will need additional generating capacity, most of which will be fossil-free.

Independent assessments conclude that no single technology can, by itself, slow and reverse increases of greenhouse gases in the atmosphere. The problem requires a portfolio of technologies and approaches, including energy efficiency and conservation, renewable resources such as wind and solar, electric vehicles and a significant expansion of nuclear power.

There is a growing realization that if we really want to reduce carbon substantially, as set out in the Paris Accord, we must lower carbon emissions by 80% by 2050, taking all fossil fuels out of electricity production. But if we're going to go carbon-free and provide adequate energy generation, it's going to take wind, solar and nuclear power.

But the increasing reliance on renewable energy has a downside because of intermittency of renewable energy and unavailability of high-capacity energy storage. At present, renewable sources are not economically competitive without subsidies. Subsidizing the costs of lower-capacity renewable sources distorts the electricity market, since it prevents the installation of high-capacity (available over 90% of the time) nuclear plants.

The Nuclear Energy Institute (NEI) suggests that the U.S. nuclear power option is not a question of "if" there is a recovery, but "when." Nuclear power plants can produce large quantities of electricity around the clock, safely and reliably. They have fuel on site and will run when needed. They provide price stability and clean air compliance. Although many of these factors are not compensated in today's market, this is likely to change. Policymakers are beginning to recognize that sustainable market design demands consideration of all the factors that constitute a robust and resilient market, including:

- Short-term price
- Long-term price stability
- Value of fuel and technology diversity
- Environmental factors

While short-run cost is an important and necessary metric, solving this complex equation for one variable only — lowest possible short-run electricity price — will not produce a reliable, resilient and affordable electricity system for the long term, according to the NEI.

Here innovation may be the key — to reintroduce innovative new technologies, such as small modular reactors, molten salt reactors, traveling wave technologies — into the nuclear power industry. Today the United States is dependent upon the old technology of Generation II light-water reactor (LWR) plants of the 1970s. Newer technologies, such as the "walk away safe" Generation III plants, are being constructed elsewhere in the world, and Generation IV plants need to be developed. Yet in the United States, the entire licensing and regulatory process is tied to the needs of Gen II LWRs. This makes it almost impossible to earn a license for anything but old technology.

In 2016, the U.S. House of Representatives passed the Advanced Nuclear Technology Development Act directing the Nuclear Regulatory Commission to collaborate with the DOE to support development and deployment of advanced reactors, including testing and demonstration on federal laboratory sites. Examples of such reactors include molten salt and modular reactors that provide cheap, meltdown-proof and waste-free nuclear power. During a Senate committee hearing, Senator Lamar Alexander stated the challenge succinctly: "The United States should build more reactors, relieve the burdens of expensive regulations, stop picking winners and double energy research. If we do these things, the U.S. won't be without nuclear power and our energy future will be bright."

Appendix C

The Phoenix Memorial Energy Institute

One of the most significant achievements of the University of Michigan was the creation of the Michigan Memorial Phoenix Project, one of the nation's first research programs in the peaceful applications of atomic energy. This research institute was created and funded through private contributions as the memorial to the 579 members of the University of Michigan family who had given their lives to the nation in World War II.

Although the nature of the Phoenix Project as both a world-class research center and a war memorial had been an extremely important achievement of the University for the past half century, in 2002 a decision was made by the University leadership to decommission the Phoenix Project's most important asset, the Ford Nuclear Reactor. Although this decision was strongly opposed not only by the nation's scientific community but also by the U.S. Department of Energy, which offered to fund the continued operation of the reactor, the University went ahead, eventually spending over $23 million to complete the decommissioning.

Beyond the loss of a valuable research facility to the nation, decommissioning the Ford Nuclear Reactor put at risk the very existence of the University's WWII war memorial since the reactor facility was the cornerstone of the Phoenix Memorial Laboratory. To preserve this important memorial, in 2003 the University commissioned a special faculty committee, the Michigan Energy Research Council, to develop a plan to redefine the Michigan Memorial Phoenix Project as a broader, University-wide organization. The resulting Phoenix Memorial Energy Research Institute would be dedicated not only to developing and sustaining a broad array of research in energy science, technology and policy, but also to preserve the WWII war memorial nature of the original Phoenix Project.

In this appendix we have included both the original recommendation of the Michigan Energy Research Council (MERC) as well as the response of the University's Board of Regents to creating the Phoenix Memorial Energy Research Institute.

Unfortunately, however, since the new institute was created as a University energy research center, housed in the Phoenix Memorial Laboratory and augmented with an adjacent office and meeting facility, the new institute's connection to and manifestation of the earlier Phoenix war memorial was eroded. Soon the name of the institute was changed to the "Michigan Energy Institute," losing the memorial identity altogether, leaving only a small endowment to represent the original Michigan Memorial Phoenix Project. In fact, during the University's Bicentennial Celebration in 2017, there was even an effort to portray the history of the original Phoenix Project as an element of the nation's nuclear weapons research program, an alarming contrast to its creation as the nation's first effort to explore peaceful uses of atomic energy.

Since the Michigan Memorial Phoenix Project and the Phoenix Memorial Laboratory were so closely related to the University's Department of Nuclear Engineering and Radiological Sciences over most of its history, we believe it appropriate to challenge the University to re-establish the energy institute and its facilities as the "Phoenix Project" memorial to those University of Michigan students, faculty, staff and alumni who gave their lives to protect our nation in WWII. To forget this memorial and the sacrifices it acknowledges would do great damage to the University's history.

The Statement of the University's Michigan Energy Research Council

There are few contemporary challenges facing our state, the nation, and the world more threatening than the unsustainable nature of our current energy infrastructure. Every aspect of contemporary society is dependent upon the availability of clean, affordable, flexible, and sustainable energy resources. Yet our current energy infrastructure, heavily dependent upon fossil fuels, is unsustainable. Global oil production is expected to peak within the next several decades, with natural gas production peaking soon afterwards. While there are substantial reserves of coal and tar sands, the mining, processing, and burning of these fossil fuels poses increasingly unacceptable risk to both humankind and the environment, particularly within the context of global climate change. Furthermore, the security of our nation is threatened by our reliance on foreign energy imports from unstable regions of the world, particularly in the Middle East.

The likely collapse of our fossil fuel energy economy poses a particular challenge for the state of Michigan, still heavily dependent upon the automobile industry. Ground transportation utilizes 50% of the petroleum consumed in the United States. Furthermore, the Great Lakes states are both the largest producer and consumer of electrical power, primarily dependent upon coal-fired plants. Hence the implications of the unsustainable nature of fossil fuels are very serious for the future of our state.

Given this urgency, we believe the University of Michigan has both the obligation and opportunity to build a world-class capability in energy research, with a particular focus on advanced energy sources, more efficient energy utilization, energy policy, and global sustainability. Furthermore, such an endeavor would align well with numerous evolving research and funding opportunities aimed at clean and renewable energy generation and efficient utilization in both government and industry. It would also hold the potential of both sustaining many of Michigan's existing industries while stimulating new regional economic activity in energy technologies. It would also assist the State of Michigan in charting its course for job growth and economic stability relevant to our future energy needs.

Thus, the University of Michigan must build its strength in three important areas. First, we must continue to attract and develop our expertise in emerging areas of energy research. Second, we must develop institutional structures to coordinate and advocate energy research both within and outside the university. Third, we must provide flexible resources that can be dedicated to developing and sustaining a broad array of research in energy science, technology, and policy.

The Michigan Energy Research Council endorses the initiative proposed by the Vice President for Research to build focused strength in key areas of energy research that will complement existing strengths. The Office of the Vice President for Research will work with the Schools and Colleges to bring to Michigan leading researchers who can help grow world-class research programs in emerging areas of energy research.

Broad based support for the energy sciences, technology, and policy at the University of Michigan will be provided with the formation of a new research institute — the Phoenix Memorial Energy Institute. Positioning Michigan as a leader in energy research requires a structure capable of supporting and expanding multidisciplinary research. To accomplish this, the proposed Institute will be an enabling rather than an operational or managing organization. It will be a focusing mechanism for the broad spectrum of University energy expertise and programs. Its functions would be to coordinate (research projects, partners, or clients), to serve as a clearinghouse linking expertise both on and off campus, to assist in identifying and developing research opportunities (perhaps enabled with seed funding), to market the University's capabilities in energy research (to government, industry, and the public), to stimulate the development of educational programs, and to manage those facilities designed to support University-wide, multidisciplinary research activities.

The Phoenix Memorial Energy Institute will build on the legacy of the Michigan Memorial Phoenix Project, founded at the end of World War II, which was devoted to the peaceful use of nuclear energy. This opportunity was provided in a Regental action in 2006 that broadened the charter of the Phoenix Project, Michigan's World

War II Memorial, beyond atomic energy to encompass "research on the development of energy policies that will promote world peace, the responsible use of the environment, and economic prosperity." The new charter furthermore stresses interdisciplinary research and education that encompasses "perspectives from the natural and social sciences, engineering, medicine, and the arts and humanities." To this end, the Phoenix Memorial Laboratory is already being renovated with State of Michigan and University funding to become a multipurpose energy research laboratory.

Rededication of the Phoenix Institute would be accompanied by a campaign to re-establish a significant endowment that would be used to underwrite the activities of the institute and support energy research across the campus. Our goal would be to endow the institute with at least $70 million, which is the value of the original endowment in today's dollars. Revenue generated by this endowment would be used to support the activities of the institute and provide a pool of flexible resources that will be deployed to develop and sustain a broad range of energy research.

The Regents Resolution (July 2006)

Regents Information Item: In May, 1948, the Regents of the University of Michigan resolved that "the University of Michigan create a War Memorial Center to explore the ways and means by which the potentialities of atomic energy may become a beneficent influence in the life of man, to be known as the Phoenix Project of the University of Michigan." Construction of the Michigan Memorial Phoenix Project (MMPP) laboratory was completed in 1951. The Ford Nuclear Reactor became part of the project when it went critical in 1957 and served researchers until it was deactivated in July of 2003.

Since the establishment of MMPP, significant progress has been made in putting atomic/nuclear energy to use for peaceful purposes. Today nuclear science is used routinely in medicine, engineering, geology, anthropology, and a host of other fields, to advance knowledge and improve the human condition. Such progress not withstanding, two major challenges embodied in MMPP remain as relevant and intractable today as they were in the late 1940s: the need for a viable, long-term energy policy and the continued need to find ways for people and nations to live together peacefully.

To assure that its WW II memorial remain a relevant and lasting tribute to those who fought and gave their lives during the War, the University will refocus the mission of MMPP to include research on the development of energy sources and energy policies that will promote world peace, the responsible use of the environment, and economic prosperity. In doing so, it is envisioned that MMPP will become the coordinating center for research activities from a variety of disciplines that are presently dispersed across multiple schools and colleges. Research areas will include energy generation from sources such as nuclear, hydrogen, solar, wind, and geothermal, as well as energy storage, energy management, and energy policy. Research perspectives will continue to encompass the natural and social sciences, engineering, medicine, and the arts and humanities.

Michigan Energy Research Council members 2005 – 2006:

James J. Duderstadt (Chair)
University Professor and President Emeritus
Meigan Aronson
Associate Dean for Natural Sciences
Dennis N. Assanis
Chair and Professor, Mechanical Engineering
Arvind Atreya
Professor, Mechanical Engineering
Mark Burnham
Director, Federal Relations for Research
Steve Ceccio
Associate Vice President for Research
David Cole
Environmental Research Institute of Michigan
Bob Culver
Tauber Manufacturing institute
Andrew J. Hoffman
Associate Professor, Ross School of Business
Gregory A. Keoleian
Associate Professor
School of Natural Resources & Environment
James C. MacBain
Director, Engineering Research Relations
Jerry Mader
Energy Research Director, Engineering
James Penner-Hahn
Chair, Biophysics Research Division

Barry G. Rabe
Professor, Natural Resources & Environment
Ann Marie Sastry
Associate Professor, Mechanical Engineering
Johannes W. Schwank
Professor, Chemical Engineering
Anna Stefanopoulou
Associate Professor, Mechanical Engineering

The Michigan Energy Institute

MEI adjacent to Michigan Memorial Phoenix Project

The MEI Laboratories

Television monitors of MEI activities

A sign joining MMPP and NEL

An artist's mistaken concept of the MMPP

Evolution of the MMPP, MEI, and NEL

Appendix D

Faculty Honors and Awards

Early Faculty Members (Chronological Order)

Henry Gomberg
- Henry Russell Award, UM

William Kerr
- Arthur Holly Compton Award, ANS
- ANS Fellow
- Meritorius Service Award, NRC

Paul Zweifel
- E. O. Lawrence Award, DOE

John King
- ANS Fellow
- APS Fellow
- Research Excellence Award, UM

Chihiro Kikuchi
- ANS Fellow
- APS Fellow
- Ruby Maser Exhibit, Smithsonian

Richard Osborn
- ANS Fellow
- APS Fellow
- Western Electric Award, ASEE
- Goebel Chair in Engineering

Glenn Knoll
- ANS Fellow
- IEEE Fellow
- Arthur Holly Compton Award, ANS
- Glenn Murphy Award, ASEE

Terry Kammash
- APS Fellow
- ANS Fellow
- AIAA Fellow
- NASA Institute for Advanced Concepts Fellow
- Seaborg Award, ANS
- Arthur Holly Compton Award, ANS
- Outstanding Achievement Award, Fusion Energy Division, ANS
- Research Excellence Award, UM
- Steven Attwood Chair

Jack Carpenter
- ANS Fellow
- APS Fellow
- AAAS Fellow
- Faculty Recognition Award, UM
- Engineering Alumni Society Award, UM
- Distinguished Performance Award, U Chicago
- Illya Frank Award, Russia
- Clifford Shull Prize, Neutron Scattering Society

Ziya Akcasu
- ANS Fellow
- APS Fellow
- * Special Session of American Chemical Society to honor 70th birthday
- * Research Excellence Award, COE (1995)
- * Science Award from Association of Turkish-American Scientists (1993)
- * Science Award of Research Council of Turkey (1992)
- *Alexander von Humboldt Award for outstanding research by scientist outside Europe (1991)
- * Glenn Murphy Award, ASEE (1986)

Current Faculty Members (Alphabetical)

Michel Atzmon

* By-Fellow, Churchill College, Cambridge, UK
* Excellence in Research Award, NERS
* Engineering and Physical Science Research Council's Visiting Research Fellowship, UK, (1996-97)

Alex Bielajew

* Fellow, Institute of Physics, UK (1999)
* Achievement Award for improvement of international radiation standards for cancer therapy, National Research Council of Canada (1994)
* Sylvia Fedoruk Prize in Medical Physics (1991, 1989)
* Farrington Daniels Award (1985)

Thomas Downar

* Fellow, ANS (2002)
* Best Paper Award, ANS Annual Meeting, Reactor Physics Division (1995, 96)
* Best Teacher Award, School of Nuclear Engineering, Purdue(1989, 90, 92)
* Hertz Fellow, MIT (1980-84)
* Best Teacher Award, U.S. Military Academy (1980)

James Duderstadt

* Fellow, ANS (1983)
* Fellow, AAAS (1993)
* Member, National Academy of Engineering (1987)
* Member, American Academy of Arts and Sciences (1993)
* Vannevar Bush Award, National Science Board (2015)
* National Medal of Technology, US President (1991)
* National Engineer of the Year, NSPE(1991)
* E.O. Lawrence Award, DOE (1986)
* Arthur Holly Compton Prize, ANS (1985)
* Mark Mills Award, ANS (1968)

Rodney Ewing

* Member, National Academy of Engineering (2017)
*Ian Campbell Medal, American Geosicences Institute (2015)
* Edward H. Kraus Distinguished University Professor, UM (2009-2013)
* Fellow, Materials Research Society (2008)
* Fellow, American Geophysical Union (2007)
* Fellow, AAAS (2004)

Ronald Fleming
* Research Award, National Institute of Standards and Technology (2008)

John Foster

* UM NERS Outstanding Achievement Award (2014)
* NASA Faculty Fellow Award (2010, 2011, 2012-2013, 2014)
* Nuclear Engineering Faculty Teaching Award (2008)
* Emerald Awards Most Promising Engineer Award (2005)
* Black Engineer of the Year Special Recognition Award (2005)
* NASA Special Achievement and Performance Awards (1999-2006)
* NASA LERCIP Mentor of the Year (2004)
* NTA Physicist of the Year (2003)

Fei Gao

* Selected FZD (Forschungs zentrum Dresden-Rossendorf) Fellow, Institute of Ion Beam Physics and Materials Research, Forschungs Zentrum Rossendorf, Germany (2008-2009)
* Outstanding Research Award of Basic Energy Science, U.S. Department of Energy (2004)
* Outstanding Performance Awards, Pacific Northwest National Laboratory (2001-2003)

Ronald Gilgenbach

* Glenn F. and Gladys H. Knoll Department Chair, NERS (2018)
*Fellow, ANS (2017)

*Peter Haas Pulsed Power Award, IEEE (2017)
* Chihiro Kikuchi Collegiate Professor (2010)
* Fellow, IEEE (2006)
* Outstanding Professional Award from IEEE Southeast Michigan Section (2006)
* IEEE Plasma Science and Applications Award (1996), Fellow, American Physical Society Division of Plasma Physics (1997)
* Research Excellence Award (UM College of Engineering) (1993)
* Young Member Engineering Achievement Award from American Nuclear Society (1987)
* Presidential Young Investigator Award (1984)
* Centennial Key Award for Outstanding Young Engineer from the IEEE Nuclear and Plasma Sciences Society (1984)

Zhong He

* College of Engineering Rexford E. Hall Innovation Excellence Award, UM (2013)
* Room-Temperature Semiconductor Detector Scientist Award (2012)
* Top 100 R&D Award (PNNL & UM) (2010)
Outstanding Faculty Achievement Award, NERS, (2005)
* Alpha Nu Sigma Faculty Teaching Award, NERS students (1999 and 2003)

James Holloway

* Ted Kennedy Family Team Excellence Award (2014)
* Harold R. Johnson Diversity Service Award (2011)
* Arthur F. Thurnau Professorship, UM (2007)
* Committee on Institutional Cooperation Academic Leadership Program Fellow (2005)
* NERS Alpha Nu Sigma Faculty Teaching Award (2004, 1996, 1993, 2000)
* NERS Outstanding Achievement Award (2004)
* University of Michigan ASEE Student Chapter Annual Distinguished Lecturer (2001)
* American Nuclear Society Young Member Engineering Achievement Award (2000)
* Teaching Excellence Award, UM COE (2000)
* NERS Service Award (1997)
* 1938E Award: UM COE (1994)
* NSF Young Investigator Award (1993-1998)

Igor Jovanovic

* Bashore Faculty Development Professorship, Penn State (2010)
* Nuclear Forensics Junior Faculty Award, US Department of Homeland Security (2010)
* DARPA Young Faculty Award (2008)
* Paul Zmola Young Faculty Award, Purdue (2008)

Kimberlee Kearfott

* Good Performance Notice, Fermi II Nuclear Power Plant, Michigan Department of Environmental Quality Question on Radio-iodine Uptakes (2001)
* Service Award, University of Michigan, College of Engineering (1996)
* Career Development Award, University of Michigan (1995)
* Women's Achievement Award, American Nuclear Society (1995)
* Service Award, University of Michigan, Department of Nuclear Engineering (1994)
* U. S. Environmental Protection Agency Innovative Radon Mitigation Design Competition (1992)
* Elda E. Anderson Award, Health Physics Society (1992)
* Peter A. Neurath Award (Best Paper), New England American Association of Physicists in Medicine (1980)
* Presidential Young Investigator Award, NSF (1985-91)
* Best Paper Award, Southeast American Association of Physicists in Medicine (1991)
* Tetalman Memorial Award, Society of Nuclear Medicine (1991)
* Joseph F. Keithley Award for Adances in Measurement Science, (1988)
* Membership Recruitment Award, Health Physics Society (1989)
* Arizona Lung Association Research Award (1989)

Brian Kiedrowski

* Best Paper and Presentation, ANS Mathematics & Computational Division (Winter 2013, 2010, 2009)
* Best Engineering Presentation, Los Alamos National Laboratory Student Symposium (2008)

Karl Krushelnick

* Fellow, Optical Society of America
* Fellow, UK Institute of Physics
* Fellow: American Physical Society
* George J. Huebner Research Excellence Award, UM COE (2013)
* Outstanding Faculty Award, NERS (2010)
* Professor Mitsuyuki Abe Visiting Chair, Japan Atomic Energy Agency, Kyoto Japan (2008-2011)
* Charles V. Boys medal and prize for experimental physics – UK Institute of Physics (2006)
* Berman research publication award, US Naval Research Laboratory (1997)

Mark Kushner

* Stephen S. Attwood Award, COE (2018)
* Distinguished Visiting Professor, Instituto Superior Tecnico (Lisbon), (2017)
*Distinguished Technical Lecture, North Carolina State (2017)
*Doctor Honoris Cause, Eindhoven University of Technology, The Netherlands (2016)
*Distinguished Lecturer, APS Plasma Physics (2016)
*Bikerman Lecture, Case Western Reserve (2016)
* Charles K. Birdsall Award, IEEE, Plasma Science and Applications, 2015
* National Academy of Engineering, 2011
* Will Allis Prize, APS (2010)
* Medard Welch Award, American Vacuum Society 2010
* Alumni Academic Achievement Award, 2009 UCLA College of Engineering
* University Researcher Award, 2008 Semiconductor Industry Association
* SRC Student Symposium, Best-in-Session Award (2005, 2006)
* AVS Distinguished Lecturer (2001-2003)
* IEEE Plasma Science and Applications Award (2000)
* Institute of Electrical and Electronics Engineers

Edward Larsen

* Eugene P. Wigner Reactor Physicist Award, ANS (2009)
* Special Recognition Award, Mathematics and Computation Division, ANS (1999)
* Arthur Holly Compton Award, ANS (1996)
* E.O. Lawrence Award, U.S. Department of Energy (1994)
* Excellence in Research Award, UM COE (1993)
* Excellence in Teaching Award, UM COE (1989)
* Fellow, ANS (1988)

Yue Ying Lau

* Fellow, APS (1986)
* Fellow, IEEE (2008)
* IEEE Plasma Science and Application Award (1999)
* Sigma Xi Society Applied Science Award (1989)
*Excellence in Research Award, COE (1986)

John Lee

* Fellow, ANS (1988)
*Arthur Holly Compton Award, ANS (2015)
* Distinguished Alumnus Award, College of Engineering, Seoul National University (2010)
* Outstanding Faculty Achievement Award, UM COE (2008)
* Outstanding Teacher Award, NERS (2006 and 2007)
* Outstanding Service Award, NERS, University of Michigan (1998)
* Class of 1938E Distinguished Service Award, UM COE (1979)

Annalisa Manera

* Ted Kennedy Family Faculty Excellence Award, UM (2017)
* Outstanding Achievement Award, NERS (2016)
* Director’s Award, DOE CASL Project (2016)

Willliam R. Martin

* Fellow, ANS (1995)
* Outstanding Faculty Award, NERS (2013)
* Outstanding Faculty Award, NERS (2002)
* Glenn Murphy Award for Outstanding Contributions to the Profession and Teaching of Nuclear Engineering, American Society for Engineering Education (1993)
* Royal Society Visiting Scholar, Imperial College, London (1989)

Martha Matuszak

*Best of ASTRO Award (Senior Author) (2017)
*NRG Oncology Outstanding Publication Award (Senior Author) (2017)
*Medical Physics Teacher of the Year, Department of Radiation Oncology, UM (2011)

Ryan McBride

*Young Investigator Award, Office of Naval Research (2018)
*Sandia National Laboratories Employee Recognition Award (2013, 2014, 2016)
*DOE NNSA Defense Programs Award of Excellence (2011, 2014)
*Sandia National Laboratories Certificate of Excellence (2014)
*MAID "Nauka/Interperiodica" Pleiades Publishing Award for Best Paper (2012)

Sara Pozzi

* Fellow, ANS (2017)
* IEEE-NPSS Distinguished Lecturer (2016)
* Fall Ohanian Lecture, Herbert Wertheim College of Engineering, University of Florida (2016)
* Elsevier, Selected for Virtual Special Issue on Women in Physics (2016)
* Institute of Nuclear Materials Management, Edway R. Johnson Meritorious Service Award (2012)
* NERS Outstanding Achievement Award (2012)
* Institute of Nuclear Materials Management Central Region Chapter, Special Service Award (2009)
* Oak Ridge National Laboratory Early Career Award for Engineering Accomplishment, September (2006)
* Scientific and Technical Award, ORNL, Nuclear Science & Technology Division, December (2006)
* Community Outreach Award, ORNL Nuclear Science and Technology Division (2006)
* Department of Energy, Office of Science, Outstanding Mentor Award (2006)
* Scientific and Technical Award, ORNL, Nuclear Science and Technology Division (2005)

Patricia Schuster

*IEEE NPSS Glenn F. Knoll Postdoctoral Grant (2017)
* UM President's Posdoctoral Fellowship (2016)

Xiaodong Sun

*Lumley Engineering Research Award, Ohio State University (2011)
*Junior Faculty Award, DOE Office of Nuclear Energy (2007)

Alec Thomas

* Young Investigator Program Air Force Office of Scientific Research (2012)
* Faculty Early Career Development Program, NSF (2011)
* PhD Research Award, European Physical Society, Plasma Physics Division (2007)
* First Place for LIDAR Technologies, Imperial College Entrepreneurs' Challenge (2002)

Lu-Min Wang

* Fellow, ANS
* Fellow, ASM
* Fellow, MRS
* Rellow, NAC
* Glenn Murphy Award, ASEE (2017)
* Mishima Award, ANS (2017)
* Excellence in Research Award, COE
*Champion H. Matthews Award, TMS
*Henry Marion Howe Medal, ASM

*Presidential Young Investigator, NSF

Gary Was

* Fellow, ANS
* Fellow, Materials Research Society (2011)
* Special Achievement Award, American Nuclear Society, MSTD (2008)
* ASM Henry Marion Howe Medal (2008)
* Walter J. Weber, Jr. Professor of Sustainable Energy, Environmental and Earth Systems Engineering
* Outstanding Faculty Member Award, NERS (2006-07)
* Significant Achievement Award, ANS, MSTD (2004)
* Champion H. Matthewson Medal, TMS (2000)
* Fellow, American Nuclear Society, NACE International, ASM International (1999)
* Teacher of the Year Award, selected by the students of NERS (1998)
* Excellence in Research Award, College of Engineering (1994)
* Presidential Young Investigator, National Science Foundation (1993)

David Wehe

*Outstanding Teaching Award, NERS (1992, 2014)
*Outstanding Faculty Award, NERS (2003)
*Outstanding Research Award, NERS (1995)
*Eugene Wigner Fellow, ORNL (1994)
* State of Michigan Excellence in Teaching/Research Award (1991)
* First military tenured faculty member, U.S. Naval Academy (1990)

Won Sik Yang

* Fellow, ANS
*Pacesetter Award, Argonne National Laboratory (2004, 2011)
* Best Paper Award, ANS Annual Meeting, Reactor Physics Division (2004)
* Special Session on work, American Chemical Society
* Research Excellence Award, COE (1995)
* Science Award, Research Council, Turkey, (199)

NERS Honors and Awards Funds (and donors)

William Kerr Scholarship Fund (Kerr family and friends) 2004
Glenn Knoll Undergraduate Scholarship (Gladys Hetzner Knoll) 2014
John C. Lee Fellowship Fund (Frederick W. and Marion K. Buckman) 2015
Edward W. Larsen Tribute Fund (Dr. Todd A. and Stephanie B. Wareing) 2015
William Martin Fellowship Fund (Frederick W. and Marion K. Buckman) 2017
Don Kania & Renee DuBois Fellowship Fund (Don R. Kania and Renee L. DuBois) 2015
Paul and Karen Fessler Endowed Student Support Fund (Paul and Karen Fessler) 2017
Thomas and Noelle Mehlhorn Scholarship (Tom and Noelle Mehlhorn) 2015
Chihiro Kikuchi Scholarship Fund 1987
John S. King Scholarship Fund (Elizabeth King, John S. King, Jr., Frances King) 1988
Jaya Ramanuja Nuclear Engineering and Radiological Sciences Student Support Fund (Jaya Ramanuja) 2014
Ziya Akcasu Fellowship Fund (Sidney Yip) 2018
James D. Butt Scholarship Fund (James D. Butt) 2007
Sidney and Nenita Yip Junior Faculty Award Fund (Sidney Yip) 2018

Appendix E

Publications Authored by NERS Faculty Members

Books

1966 Osborn, Richard K. and Sidney Yip, *The Foundations of Neutron Transport Theory* (Gordon and Breach)

1967 Case, Kenneth M. and Paul F. Zweifel, *Linear Transport Theory* (Addison-Wesley, Reading)

1971 Akcasu, Ziya, Gerald S. Lellouche, Louis M. Shotkin, *Mathematical Methods in Nuclear Reactor Dynamics* (Academic Press, 1971)

1973 Duderstadt, James J. and Louis J. Hamilton, *Nuclear Reactor Analysis* X-rated Course Notes Vol 1 (UM Department of Nuclear Engineering) http://hdl.handle.net/2027.42/120924

1973 Duderstadt, James J. and Louis J. Hamilton, *Nuclear Reactor Analysis* X-rated Vol 2 (UM Department of Nuclear Engineering) http://hdl.handle.net/2027.42/120925

1975, Duderstadt, James J. and Louis J. Hamilton, *Nuclear Reactor Analysis* (John Wiley, New York, 1975) http://hdl.handle.net/2027.42/138092

1976, Kammsh, Fusion Reactor Physics (Ann Arbor Science, Ann Arbor)

1979 Duderstadt, James J. and Chihiro Kikuchi, *Nuclear Power Technology on Trial* (University of Michigan Press, Ann Arbor, 1979) http://hdl.handle.net/2027.42/120927

1979 Duderstadt, James J., *Nuclear Power* (M. Dekker)

1979 Duderstadt, James J., William R. Martin, *Transport Theory* (John Wiley, New York) https://babel.hathitrust.org/cgi/pt?id=mdp.39015040316401;view=1up;seq=5

1982 Duderstadt, James J., Gregory Moses, *Inertial Confinement Fusion* (John Wiley, New York) http://hdl.handle.net/2027.42/120928

1982 Duderstadt, James J., Glenn F. Knoll, and George S. Springer, *Principles of Engineering* (John Wiley, New York) https://babel.hathitrust.org/cgi/pt?id=mdp.39015000500663;view=1up;seq=7

1984 Duderstadt, James J. and William R. Martin, *Nuclear Reactor Analysis 1 Workbook* (Department of Nuclear Engineering Video Course) http://hdl.handle.net/2027.42/138090

1984 Duderstadt, James J. and William R. Martin, *Nuclear Reactor Analysis 2 Workbook* (Department of Nuclear Engineering Video Course) http://hdl.handle.net/2027.42/138091

1984 Martin, William R.. and James J. Duderstadt, *Thermal Analysis of Nuclear Reactors Workbook* (Department of Nuclear Engineering Video Course) http://hdl.handle.net/2027.42/138092

1984 Martin, William R.. and James J. Duderstadt, *Reactor Fluid Mechanics Workbook* (Department of

Nuclear Engineering Video Course)
http://hdl.handle.net/2027.42/138093

1979 Knoll, Glenn F., *Radiation Detection and Measurement* (John Wiley, New York; with numerous later editions up to 4th Edition 2011)

1995 Kammash, Terry, Editor, Fusion Energy in Space Propulsion (Amerin Institute of Aeronautics and Astronautics, Washington, D.C.)

2007 Was, Gary S., *Fundamentals of Radiation Materials Science: Metals and Alloys* (Springer, New York, 2007, 2017)

2011 Lee, John C., and Norman J. McCormick, *Risk and Safety Analysis of Nuclear Systems* (John Wiley, New York)

2011 Han, Charles, and A. Ziya Akcasu (John Wiley & Sons (Asia)

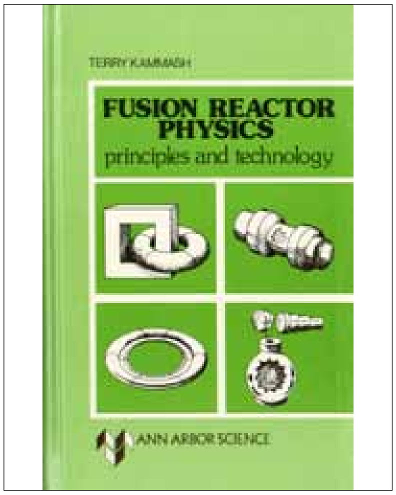
Web Productions

University of Michigan Millennium Project
http://milproj.dc.umich.edu

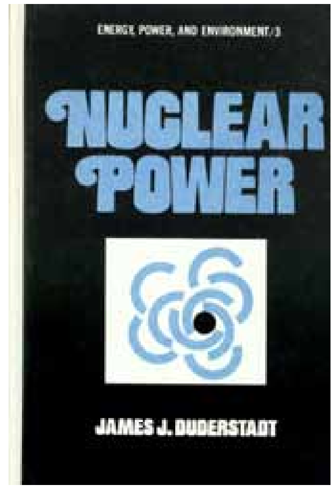
Video Productions

1977 James J. Duderstadt, *Nuclear Power and You*, A five program production by University of Michigan Television produced for public television
http://milproj.dc.umich.edu/Nuclear_Power/

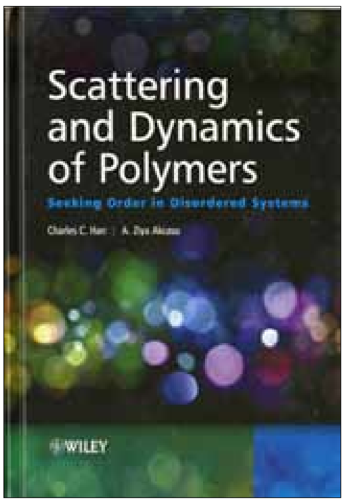
2015 *Vannevar Bush Award* to James J. Duderstadt for a Lifetime of Public Service (National Science Foundation)
https://www.youtube.com/watch?v=EIvfRuG7WNQ



Fusion Reactor Physics (Kammash)



Nuclear Power (Duderstadt)



Scattering of Polymers (Han and Akcasu)

Fusion Energy in Space (Kammash)

A congratulations photo by former students of the election of Jim Duderstadt as Michigan President (1988)

Appendix F

50 Year History of the NERS Department

(Prepared for the 50th Anniversary of the Department)

The Department of Nuclear Engineering and Radiological Sciences at the University of Michigan is the oldest degree program and the second oldest department of its type in the country. In the late 1940s the Department of Aeronautical Engineering organized a graduate program for Air Force officers who came to the University for training. One of the courses offered was a course that began with introductory material in neutron-nuclear physics and included some material on reactor physics, such as diffusion theory and elementary criticality calculations. The course was first held on a classified basis, and was organized and taught by Larry Rauch and Myron Nichols.

In the early 1950s, when the material became available on an unclassified basis, it was decided to offer the course on a college-wide basis. Developing interest in nuclear energy led to the introduction of several additional courses including a Radiation Measurements course, taught in Electrical Engineering (Kerr), a course on Interaction of Radiation with Matter, taught in Electrical Engineering (Gomberg), and a course on Industrial Applications of Radiation taught in Chemical Engineering (Brownell).

Interest in the area grew to the point that an interdepartmental Committee was appointed by the Dean of Engineering in 1952 to administer a graduate program in Nuclear Engineering. It was decided in the early 1950s to construct a research reactor, as part of the Michigan Memorial Phoenix Project (MMPP) established as a World War II memorial in 1948. The existence on campus of a program with the responsibility for developing peaceful uses of nuclear energy attracted additional attention and a significant number of graduate students to the Nuclear Engineering program. The Ford Nuclear Reactor (FNR), built with a $1 million grant from the Ford Motor Company, reached an initial criticality in 1957 and was the third university campus reactor constructed in the United States.

The first Masters degree in Nuclear Engineering was awarded in 1954. The first three Ph.D. degrees (to M. Iriarte, T. Kammash, and F. Hammitt) were awarded at the spring commencement in 1958. By 1958 about 110 graduate students were enrolled, and about eight faculty members were associated with the program on at least a part-time basis: Gomberg, Kerr, King, Zweifel, E. Martin, Osborn, Brownell, and West.

In early 1958 the Engineering College and the University administration approved the formation of a Department of Nuclear Engineering, and it came into being officially on July 1, 1958. Henry Gomberg was appointed the inaugural Department Chairman.

The first student chapter of the American Nuclear Society was organized at the University of Michigan, and was officially chartered in December 1955. The Department initially offered only a graduate program, with degrees at the Masters, professional, and doctoral levels. It was a national leader in the establishment of Ph.D. programs in Nuclear Engineering and in Nuclear Science. In 1959, a tradition of long standing was begun by the administration of a "preliminary" examination for the incoming class of doctoral candidates (including Carpenter, Pluta, Knoll, Plummer, Ferziger, Stevens, Borcherts, Olhoeft, and Albrecht).

In the Fall of 1965, the undergraduate program in Nuclear Engineering was established. The first B.S. degrees were awarded two years later. A second undergraduate program, in Engineering Physics, formerly Science Engineering, was reinstituted in 1980 under the auspices of the Department of Nuclear Engineering. In the 1980s, teaching and research programs of the Department began to diversify significantly outside the traditional nuclear engineering areas, including plasma physics, materials science, radiation measurements, radiological health, and medical physics. In recognition of the program diversification, the Departmental name was changed in 1995 to the Department of Nuclear Engineering and Radiological Sciences.

Throughout its history, the Department has been housed on North Campus, close to the Phoenix Memorial Laboratory (PML) and the FNR. Initially, the Departmental office was located in the Automotive Laboratory, with faculty offices and laboratories also housed in the PML and the Fluids Laboratory (now G. G. Brown Laboratory). A major relocation took place in 1977 with the move of the Departmental office and most faculty offices to the Cooley Building. At the same time, major laboratories not located in the PML were transferred to the large shielded bays that formerly housed the Physics Department cyclotrons.

The Departmental research laboratories in the former cyclotron bays evolved into the Michigan Ion Beam Laboratory and the Plasma, Pulsed Power and Microwave Laboratory, occupying a large part of the Naval Architecture and Marine Engineering (NAME) Building. As a major University-wide facility, the FNR operated successfully between 1957 and 2003, when it was shut down for decommissioning. The Neutron Science Laboratory, featuring a D-T neutron generator with associated shielding facilities, was added recently to the Departmental facilities in the NAME Building. NERS faculty members also play leadership roles in a number of University facilities, including the Center for Ultrafast Optical Sciences (CUOS) and the Electron Microbeam Analysis Laboratory (EMAL).

In addition to the current faculty, a number of individuals served on the departmental faculty. They include George West (died in 1970), Louis Hamilton (died in 1973), Lloyd Brownell (died in 1976), Edward A. Martin (died in 1985), Richard K. Osborn (died in 1987), Chihiro Kikuchi (died in 1988), Fred Hammitt (died in 1989), Milton Edlund (died in 1993), Henry Gomberg (died in 1995), George Summerfield (died in 1996), Fred Shure (died in 2000), John King (died in 2007), Geza Gyorey (retired from General Electric Company), Paul Zweifel (now at Virginia Tech), Harvey Graves (retired), Jack Carpenter (now at Argonne National Laboratory), David Bach (semi-retired at California State University, Northridge), M. M. R. Williams (now at Imperial College of Science, Technology and Medicine), Mary Brake (now at Eastern Michigan University), Rodney Ewing (now with the Geology Department with a joint position in NERS), and Donald Umstadter (now at the University of Nebraska). The department also has 4 adjunct faculty and 5 research scientists contributing to various instructional and research programs.

The Department has been headed by seven Chairs over its history: Henry Gomberg (1958-1961), William Kerr (1961-1974), John King (1974-1979), Glenn Knoll (1979-90), William Martin (1990-94, 2004-present), Gary Was (1994-1999), and John Lee (1999-2004). James Duderstadt, a member of the Departmental faculty, served as Dean of Engineering (1981-1986), Provost (1986-1988), and President (1988-1996).

In the half century of its history, the Department has awarded 694 B.S., 488 M.S., 4 Nuclear Engineer, and 490 Ph.D. degrees. In addition, the Department served as the home department for 189 B.S. graduates in Engineering Physics and formerly Science Engineering. During the Fall 2008 semester, the Department has a total enrollment of 165 undergraduates, including 30 Engineering Physics students, and 95 graduate students. The Department is consistently ranked first or second among all Nuclear degree programs in national academic surveys, including recent U. S. News and World Report surveys, both at the undergraduate and graduate levels. As one indicator of excellence, students from the Department have won the Mark Mills Award of the American Nuclear Society 12 times out of the 49 selections that have been made to date.

NERS Department Faculty in 2005

Professor Emeritus A. Ziya Akcasu	(1963)
Professor Michael Atzmon	(1987)
Professor Alex F. Bielajew	(1997)
Professor Thomas J. Downar	(2008)
Professor James J. Duderstadt	(1969)
Professor Ronald F. Fleming	(1989)
Associate Professor John Foster	(2006)
Professor Ronald M. Gilgenbach	(1980)
Assistant Professor Michael Hartman	(2007)
Professor Zhong He	(1994)
Professor James P. Holloway	(1990)
Professor Emeritus Terry Kammash	(1958)
Professor Kimberlee J. Kearfott	(1993)
Professor Emeritus William Kerr	(1953)
Professor Emeritus Glenn F. Knoll	(1962)
Professor Karl M. Krushelnick	(2006)
Professor Edward W. Larsen	(1986)
Professor Yue Ying Lau	(1992)
Professor John C. Lee	(1974)
Professor William R. Martin	(1977)
Associate Professor Sara Pozzi	(2007)
Assistant Professor Alexander Thomas	(2008)
Professor Emeritus Dietrich H. Vincent	(1960)
Professor Lumin Wang	(1997)
Professor Gary S. Was	(1980)
Professor David K. Wehe	(1986)