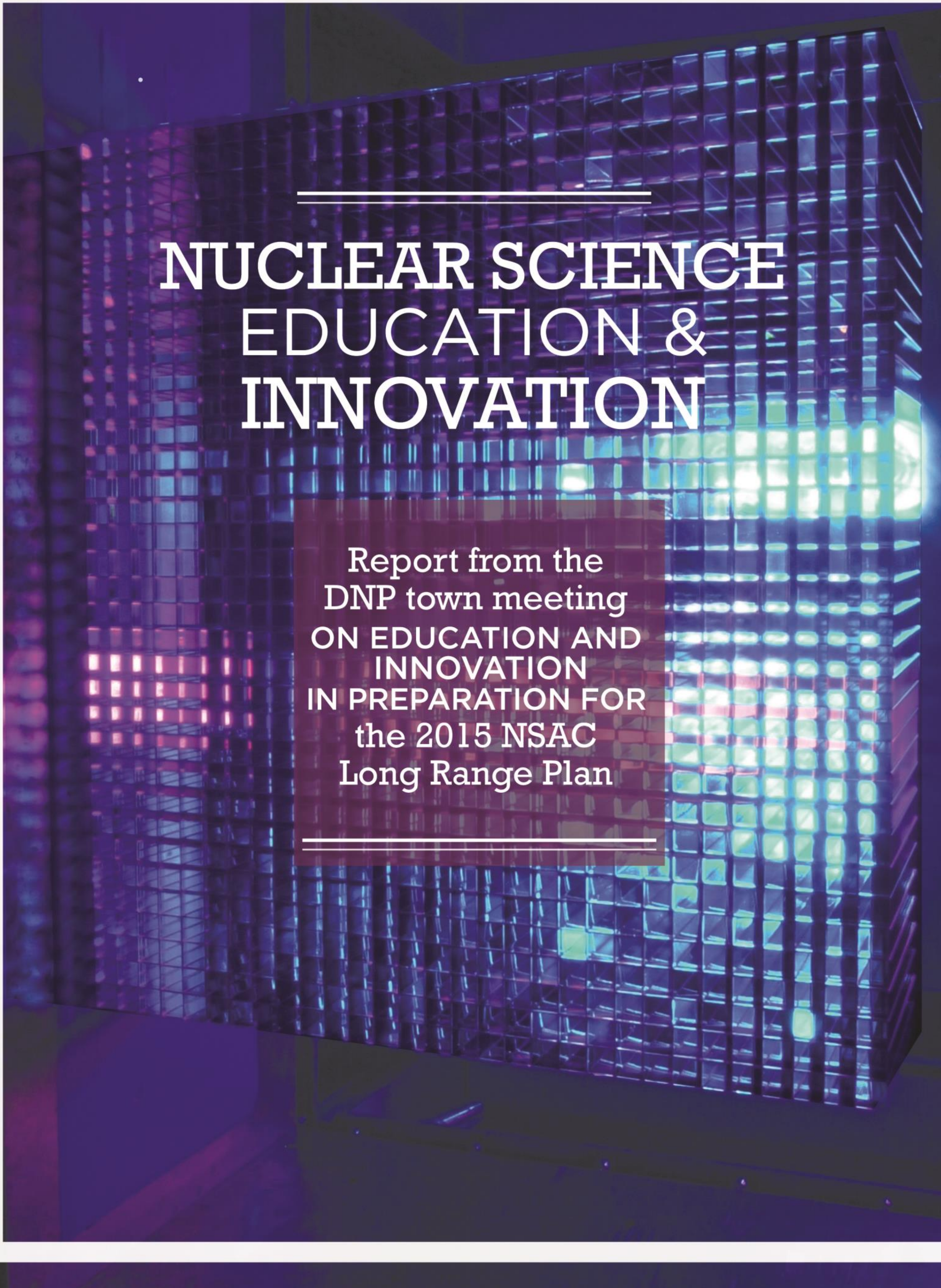

NUCLEAR SCIENCE EDUCATION & INNOVATION

Report from the DNP town meeting ON EDUCATION AND INNOVATION IN PREPARATION FOR the 2015 NSAC Long Range Plan

January 2015

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Front cover:	Photograph of lead-tungstate scintillator crystals in a support frame for the Primakoff Experiment (PrimEx) in Hall B at Jefferson Lab.

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PREAMBLE

The DNP NSAC Long Range Plan Town Meeting on Education and Innovation was held August 6–8, 2014 on the campus of Michigan State University in East Lansing, MI. It was one of four town meetings held in preparation for the 2015 NSAC Long Range Plan. While the other three town meetings concentrated on specific scientific subfields of nuclear science the Town Meeting on Education and Innovation covered topics relevant to all of nuclear science. This was the first time an official dedicated Town Meeting on Education and Innovation was held as part of the long range planning process.

The town meeting follows a long tradition within the nuclear science community to solicit ideas and initiatives from the community itself. For the 2002 long range plan a working group on education contributed to the town meeting on nuclear structure and astrophysics. In preparation for the 2007 long range plan a community driven self-organized workshop entitled "Vision for Education and Outreach in Nuclear Science" developed recommendations which were included in a white paper submitted to NSAC. In another workshop on "Enhancing American Competitiveness through Basic Research", recommendations on innovative applications of nuclear physics were summarized in a white paper submitted to NSAC. These white papers were quite influential in demonstrating the importance of education, outreach and applications in the final long range plan.

The present white paper will again serve as input to the next NSAC Long Range Plan. It highlights recent successes and new initiatives and makes specific recommendations for further advances and improvements. This white paper represents the activities, initiatives and innovative approaches presented and discussed at the town meeting. It does not claim to be a comprehensive report of all education and outreach activities in the community, nor a comprehensive review of all applications of nuclear science.

The topics of education and innovation were combined in a single town meeting because they are closely linked, representing the connection between basic nuclear science and society. About 80% of the students earning a PhD in nuclear science enter the workforce in a wide range of different fields from medicine to homeland security, while only 20% continue in fundamental research in nuclear science. At the same time, the potential for innovative practical applications, such as medicine, defense, and energy attract the best young students into nuclear science. Thus, not only does education enable creative innovations in nuclear science; these innovative applications also provide inspiration that draws students into the field to be educated. This report emphasizes the important connection between the role of education in creating future innovations in both fundamental and applied nuclear science, and the role of these applications in attracting new students into the nuclear science workforce.

The town meeting was held prior to the other three DNP scientific town meetings, so that the outcomes could be shared and discussed with everyone at these other town meetings who were not able to participate in this first meeting. The recommendations which were drafted as the outcome of the town meeting were presented to members of the whole community at the other town meetings and in a general session at the Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan in October 2014. The recommendations were modified to reflect the best sentiment expressed by the majority of the community.

Before and during the Education and Innovation town meeting, input was solicited from the whole community and contributors were asked to address the following five questions in their presentations:

- What problem do you address or try to solve?
- What specifically is the role of nuclear physics?
- What are presently the biggest impediments?
- What resources do you require in the future?
- What is your overall vision to solve the issue in the future?

The meeting consisted of a joint plenary session on workforce development and four parallel sessions on education (graduate, undergraduate, K-12, and outreach) and innovation (defense & security, energy & climate, medicine & health, and art & forensics). The program of the meeting is included in Appendix A.

The meeting itself was attended by 54 scientists with another 18 researchers contributing presentations or participating via webinar. One contribution was presented remotely via webinar. The participants represented 39 different institutions and organizations and the list of participants is provided in Appendix B. A short abstract from each of the presenters was collected after the meeting and is included in Appendix C. A special appeal to collect current nuclear science outreach activities after the meeting yielded the 50 examples shown in Appendix D.

1 EXECUTIVE SUMMARY

Nuclear science is an exciting fundamental discipline that spans all dimensions from the study of the nature of neutrinos to astrophysical objects in the universe. Scientific results of these fundamental studies and the techniques and tools developed for them have a significant impact on society. The future success of the field depends in part on the education of the next generation of outstanding scientists and the continued development of innovative applications for society.

The nuclear science community must continue to attract the best and brightest students. These students are eager and motivated to enter and to contribute to the most exciting fields of science. They are looking for opportunities to discover new phenomena, to explore areas that no one has studied before, and to develop new instruments and devices that help solve some of today's major societal problems. Traditionally, the nuclear science community has been very good at offering exciting research opportunities to students which has been greatly facilitated by long range plans. In these plans, coherent long-term strategies for the field are developed which enables optimal scientific use of existing accelerator facilities, while at the same time planning for the construction of next generation facilities. The most recent example of this successful approach to planning is the current construction of the Facility for Rare Isotope Beams (FRIB). This and other major initiatives demonstrate the continuing vitality of the field, which inspires and motivates students as they clearly see the exciting long-term research opportunities available to them.

The major funding support for students in nuclear science is provided by federal research grants. The research budgets have to be carefully balanced with the funding for the operation of existing facilities and the construction and development of future accelerators and experimental equipment. The level of research funding directly impacts the education of the students and thus strong support is essential for the overall future of the nuclear science.

Once the students enter the field, it is the responsibility of the nuclear science community to offer them an excellent education, and to provide opportunities for them to grow as scientists. These efforts should not be limited towards careers in basic science. During their time in graduate school, students develop many different strengths and interests and their education in nuclear science prepares them for a wide variety of different career opportunities. Although basic nuclear science is not the only contributor for the overall workforce in nuclear-related industries, well-educated scientists with a solid understanding of nuclear science and related skills continue to be offered excellent jobs in these industries.

The importance of education and innovation has been stressed in all previous long range plans, beginning in 1979. Based on the observations and recommendations of these long range plans, the funding agencies and the overall community have developed and established new programs, guidelines, and procedures. The well-developed plans have served the nuclear science community well and they have contributed greatly to the continuing success of the field. However, there is still room for improvement.

The following broad overarching themes were drafted at the town meeting to address some of the current issues of importance and concern in education and innovation. They will be substantiated in the subsequent sections of the report within the topics of workforce, education, and innovations. Each section describes the current status, recent progress and success, followed by detailed recommendations drafted specifically to address open issues and to develop further improvements.

HOLISTIC APPROACH TO RESEARCH

Basic nuclear science research is not performed in a vacuum. It requires a diverse range of bright, engaged scientists as well as significant resources and equipment. The research facilities and the activities are mostly federally funded. Therefore they need to be justified, and the results clearly communicated back to the agencies, the policy makers and the taxpayers. Novel technologies have to be developed and new facilities have to be designed and constructed to encourage the continuing development of cutting-edge research. Importantly, students are also being educated and young researchers are being trained to ensure future vitality and continued productivity of the field. Clearly, just performing the research itself is not sufficient.

All of the above activities are important for the future of nuclear science and they are intimately connected with the actual basic research. The researchers themselves must be actively involved in these tasks as they are the experts who understand the basic science, the necessary facilities and equipment, and the importance of the results for the broader science community and the general public.

These activities cannot be carried out by only a few within the field, and even less on a voluntary basis. All researchers should sense and embrace a responsibility to contribute to the overall effort. This does not imply that everybody has to do everything. Different scientists have different strengths, and each individual should utilize these strengths to become involved in activities beyond their own specific research agenda. Additionally, contributions from nuclear scientists with different skill sets should be appropriately acknowledged and valued.

Education and mentoring of the next generation nuclear scientists as well as dissemination of research results to a broad audience are integral parts of research. Scientists should be encouraged to engage in and be rewarded for these activities that go beyond basic research.

VISIBILITY OF NUCLEAR SCIENCE

Nuclear science is a mature field and must increasingly compete for the best and brightest students, while new fields continue to emerge not only in the traditional physical sciences but also in the more interdisciplinary areas linked to life sciences. Thus it is important for the nuclear science community to actively publicize the vitality of the field and the exciting future discovery potential it offers to students contemplating a career in physics or chemistry.

Undergraduate, graduate, as well as postdoctoral students should be included in the efforts to promote nuclear science to the general public. A majority of these students do not stay in basic nuclear science, and as they pursue careers in more applied fields, it is important for them to be aware of and promote the significant positive impact basic nuclear science research has on society.

Nuclear science is an active and vibrant field with wide applicability to many societal issues. It is critical for the future of the field that the whole community embraces and increases its promotion of nuclear science to students at all stages in their career as well as to the general public.

BROADER IMPACT

Many nuclear scientists are devoted to a wide range of activities that are not directly related to their basic research efforts. These activities demonstrate the ongoing energy and enthusiasm of researchers at universities, colleges, and national laboratories. Many have made significant contributions outside of basic science, for example in physics education research and online learning systems. In addition, many have also initiated programs within the nuclear science community to improve the overall work environment that serve as models of best practices for other fields. Examples include the CEU program and the DNP mentoring award. These efforts should continue to be valued and fostered within the nuclear science community.

There continue to be many opportunities for nuclear scientists to apply their knowledge, expertise and imagination to build on the quality of education and research in the field. The development and testing of new ideas in areas like distributed learning, high-performance computing and efforts to improve diversity especially with respect to the participation of underrepresented minorities are just a few examples.

Researchers in nuclear physics and nuclear chemistry have been innovative leaders in the full spectrum of activities that serve to educate nuclear scientists as well as other scientists and the general public in becoming informed of the importance of nuclear science. The researchers are encouraged to build on these strengths to address some of the challenges in educating an inclusive community of scientists as well as those on the path to future leadership in nuclear science.

INNOVATION AND APPLICATIONS

Many innovative techniques and methods originating from basic nuclear science research have become well established, and make significant contributions to a wide range of societal applications. In general, major breakthrough discoveries in science initially derive from pure fundamental research, with no practical applications in mind. Often, substantial additional research and development is needed to build upon the basic science to explore possible applications. Once a potential application is realized, the development of a commercial product then typically takes several more years of significant investment in resources and effort.

The initial phase of exploration is essential to the development of any application. Although several programs are available to help with the development and commercialization of new products (for example the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs), funding for this initial phase of development is becoming more difficult to obtain. Originally intended to stimulate technological innovation, the SBIR and STTR programs have over time come to place greater emphasis on commercialization. These initial research and development activities cannot be classified as fundamental research, nor do they always fall in the category of technology transfer either. This connection is especially tenuous at national laboratories where support for innovation is difficult because it is perceived as not contributing the core mission. Yet, this initial phase of application development is critical to the U.S. business enterprise where nuclear science has historically played an important role in stimulating the economy and contributing to the national business competitiveness. Additionally, this interface of nuclear science and application offers a great opportunity to attract bright and capable students to nuclear science and to teach them valuable skills in nuclear technology and innovative thinking.

The interface between basic research and exciting innovations in applied nuclear science is a particularly vital component that has driven economic development, increased national competitiveness, and attracts students into the field. It is critical that federal funding agencies provide and coordinate funding opportunities for innovative ideas for potential future applications. Where applicable they should explicitly support concurrent development of innovation from the basic research mission.

2 EDUCATION and WORKFORCE

2.1 WORKFORCE DEVELOPMENT

CURRENT STATUS

The call for a well-educated nuclear scientific workforce has been made many times over the last few years [1-5], most recently in the NSAC report "Assessment of Workforce Development Needs in the Office of Nuclear Physics Research Disciplines" [5]. The report on the "Readiness of the U.S. Nuclear Workforce for the 21st Century Challenges" stated: "There will be a continuing, long-term, significant need for nuclear scientists and engineers in industry, government, and academia, across a wide range of applications" [4], and the 2012 National Research Council (NRC) report stressed that the increasing needs for a nuclear workforce for medicine, health physics, and energy come at a time when the nuclear workforce is shrinking [1].

The nuclear science community plays an important role in the education of excellent scientists who become leaders not only in basic nuclear science in academia and national laboratories but in a broad range of applied nuclear science and related fields in industry and government. The close relationship between basic science funding and education and workforce development has been noted by previous long range plans. The 2002 plan remarked that "University based research groups and laboratories are the lifeblood of our field" [6] and the 1996 plan recommended to "Encourage the funding agencies to continue to capitalize on the direct educational benefits of their primary missions. Federal dollars spent in basic research at universities have a major impact on the quality and depth of undergraduate science education" [7]. The expertise, tools and skills acquired by PhD students during their involvement in fundamental research are highly valuable and critical to many applied areas, not only in the nuclear field but in a much broader area of society.

The 2004 NSAC Education in Nuclear Science report [8] had argued for the need to increase the number of PhDs in nuclear science by at least 20%. Instead, compared to the ten years prior to the report (1994-2003) where 840 PhDs in nuclear physics were awarded, the number during the last ten years (2004-2013) dropped 8% to 773 [9].

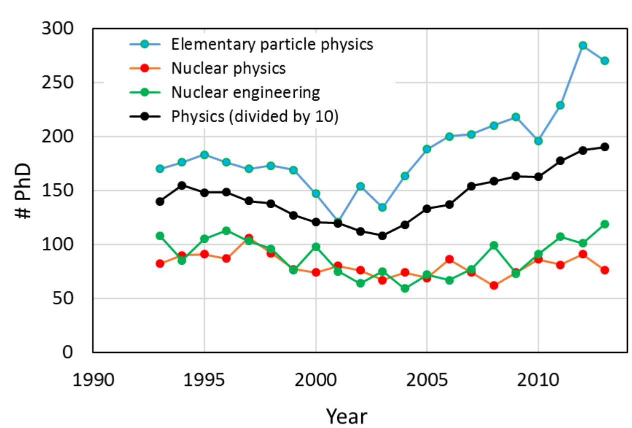


Figure 2.1.1 Number of PhD degrees awarded in elementary particle physics, nuclear physics, nuclear engineering and in physics overall [9].

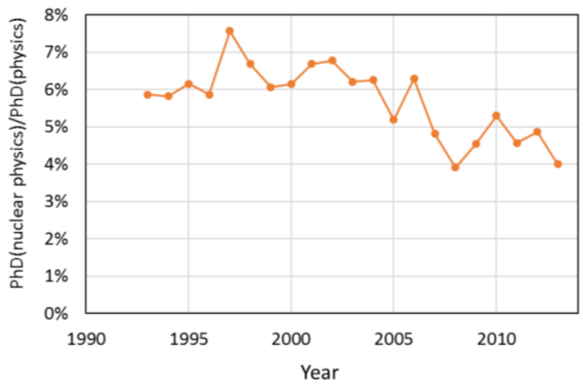


Figure 2.1.2 Fraction of all physics PhDs awarded in nuclear physics [9].

The situation is similarly concerning when the numbers of nuclear physics PhDs are compared to the numbers of PhDs awarded in physics overall. During the same time period (1994-2013) the percentage of nuclear physics PhDs relative to the total physics PhDs dropped from 6.4% to 4.9%. The yearly trends are shown in Figure 2.1.1 and Figure 2.1.2. Figure 2.1.1 shows the number of PhDs per year for nuclear physics, nuclear engineering, elementary particle physics and all of physics, and Figure 2.1.2 shows the fraction of nuclear physics PhDs relative to all physics PhDs [9].

The diminishing role of U.S. universities in producing nuclear science PhDs was already pointed out by the recent NSAC workforce report [5]. Figure 2.1.3 shows the percentage of faculty at U.S. research institutions who earned their PhD at a U.S. university in 2014 compared to the data from the 2004 NSAC education report [8]. Another indicator of the diminishing role of the U.S. universities is the decreasing fraction of early career award recipients who earned their degree in the U.S., shown in Figure 2.1.4.

The type of careers pursued by PhD recipients have not changed significantly in recent years. The most recent analysis [10] of the careers of PhD recipients 6-9 years past their degree reveals a somewhat larger fraction (47% compared to 40% in 2004 [8]) staying in academia and a smaller fraction at National Laboratories (20% compared to 27% in 2004 [8]). Figure 2.1.5 shows the distribution of chosen careers in academia, national laboratories, business/industry, and government agencies [10]. It should be mentioned that some of the differences might be due to the slightly different classification criteria. The most recent analysis included community colleges as well as university hospitals and research laboratories in the academia category.

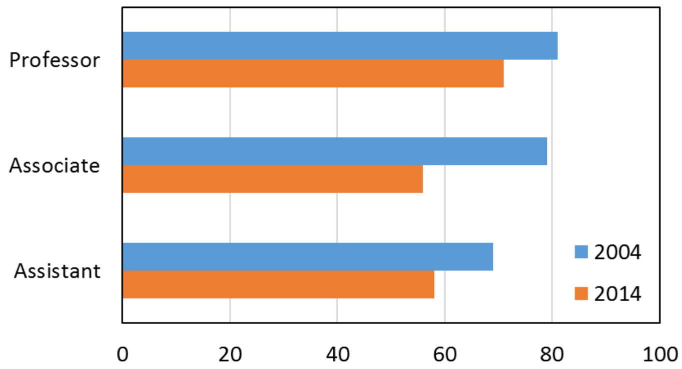


Figure 2.1.3 Percentage of faculty at U.S. research institutions who earned their PhD at a U.S. university (adapted from Ref. [5]).

Figure 2.1.4 Fraction of early career award recipients who earned their degree in the U.S. (adapted from Ref. [5]).

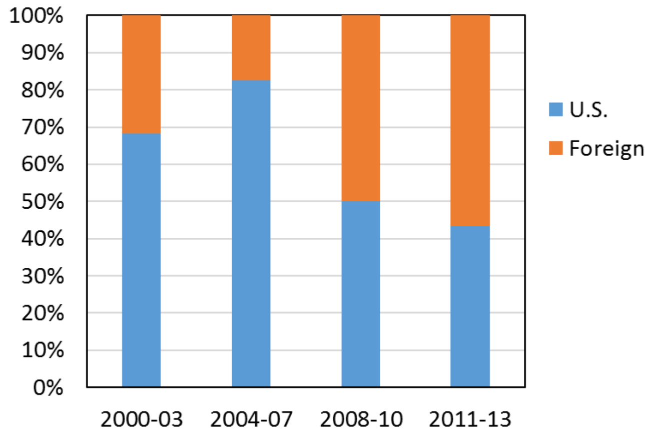
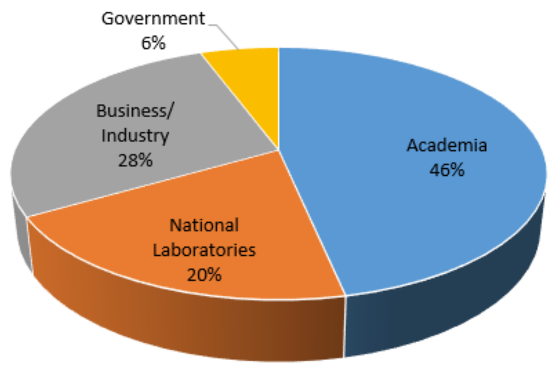


Figure 2.1.5 Distribution of careers selected by nuclear science PhD recipients [10].



The National Nuclear Security Administration (NNSA) within the Department of Energy has recognized the workforce shortfall and the critical need for highly qualified nuclear scientists. As a result it has established the Stewardship Science Academic Alliances (SSAA) [11] and more recently the National Science and Security Consortium (NSSC) [12]. These programs provide hands-on experience and training for students who form the next generation of scientists and physicists (SSAA), with the main goal of educating and training experts in the field of nuclear security (NSSC).

Within academia the number of faculty in nuclear science has also been a reason for concern. Together with the young staff scientists at the National Laboratories, assistant and associate professors at major research universities represent the future of the field. In physics, typically about 20% of the PhD recipients stay in academia [13].

Tenure track positions are major investments for universities. The decisions to fill retirement positions or create new tenure track positions in nuclear physics depend on the promise of long-term funding opportunities in basic nuclear science. The long-term exciting, important, and significant research opportunities in nuclear science should provide strong incentive for universities to not only replace retiring nuclear science faculty, but also to create new faculty positions in nuclear science.

A year ago the situation did not look very encouraging. Figure 2.1.6 compares the distribution of U.S. faculty as a function of the "year of PhD," from the NSAC education report in 2004 [9] with results from a survey in 2013 [14]. This comparison revealed that a

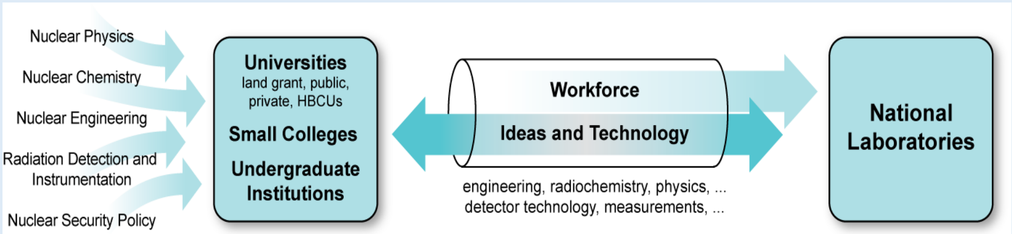
NNSA Workforce Development

Low-energy nuclear science addresses many open questions in forefront science including how elements are created and the origin of simple patterns in complex nuclei. In addition, low-energy nuclear science plays a critical role for the nation through stockpile stewardship, homeland security, nuclear forensics and the development of the next generation of nuclear reactors. Despite the importance of nuclear science to the welfare of the nation, numerous reports highlight a deficiency in the current workforce. The most recent example, the NSAC report on the Assessment of Workforce Development Needs in the Office of Nuclear Physics Research Disciplines highlights the difficulty of recruiting qualified individuals trained in nuclear science for the national laboratories and documents nuclear physics as a declining percentage of subfields for U.S. physics PhD students.

The National Nuclear Security Administration (NNSA) has made substantial investments in basic low-energy nuclear science research to develop a highly trained workforce. An example of two such programs include the Stewardship Science Academic Alliances (SSAA) [11] and the more recent National Science and Security Consortium (NSSC) led by University of California-Berkeley [12]. The pursuit of cutting edge science attracts the best and brightest students and postdocs and, when combined with national laboratory participation, establishes a career pathway of trained individuals for nuclear science positions at the national laboratories.

The NSSC brings together a broad group of disciplines including nuclear physics, chemistry, and nuclear security policy in which students have a wide variety of exposures to nuclear science problems addressing national priorities from class work to dedicated summer schools.

Within the SSAA, the Center for Radioactive Ion Beam Studies for Stewardship Science (RIBSS) brings together a group of researchers to understand the properties and decay of and reactions on fission fragments. A key feature of the RIBSS Center is immersing students in the national laboratory environment by siting them for a summer at either Livermore or Los Alamos NNSA laboratories. The SSAA also supports individual investigator projects and the Stewardship Science Graduate Research Fellowships. PhD alumni from all of these NNSA-supported programs have careers in academia, national laboratories, and industry [16].



Relationship between the universities and colleges and the National Laboratories [16]

Figure 2.1.6 Distribution of U.S. faculty as a function of "year-of-PhD" from the 2004 NSAC education report [8] and the 2013 survey [14].

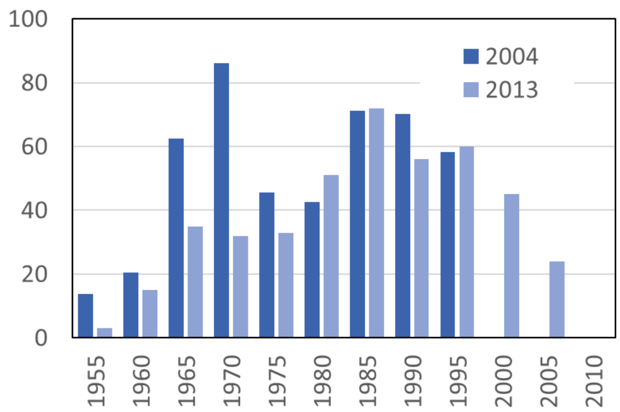
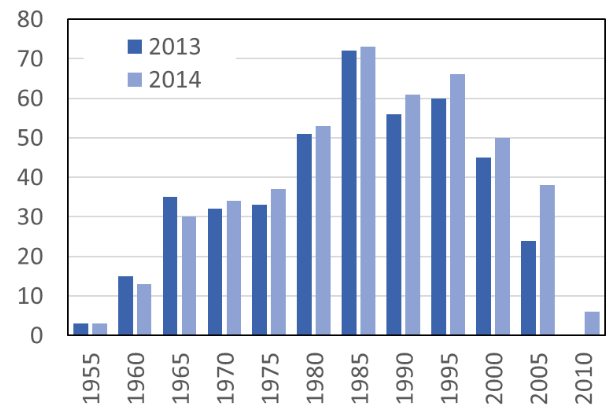


Figure 2.1.7 Distribution of U.S. faculty as a function of "year-of-PhD" in 2013 [14] and 2014 [15].



large number of faculty who received their PhD prior to 1980 have retired during the last 10 years, while only a fraction of them had been replaced, thus representing an overall drop in the number of nuclear science faculty. Approximately 110 retirements have occurred since 2004, while only approximately 70 new hires were made during that same period, pointing to a very concerning decrease in the overall number of nuclear science faculty.

This trend seems to have been reversed during the last year [15] where only a few more faculty retired but a significant number of new faculty were hired (see Figure 2.1.7). While during the last ten years on the average about 7 PhD recipients were hired into faculty positions per year; the 25 new hires in 2014 increase that number to about an average of 9 new hires per year. This is certainly very encouraging, and points to a bright future for the field.

DIVERSITY

Another important aspect of the scientific workforce is diversity. The number of female faculty in physics represents only a small fraction of the total faculty. In 2007, the APS Committee of the Status of Women in Physics (CSWP) set a goal to double the number of women in academia and national laboratories over the next fifteen years [17].

In the past the demographics for nuclear physics have more or less followed the overall trend in physics, although have fallen behind more recently. Table 2.1.1 shows the fraction of female faculty in all of physics [18] compared with those in nuclear physics [14]. Noticably, the fraction of female assistant professors is larger for nuclear physics.

	Percent female faculty	
	Physics	Nuclear Physics
Full Professor	8%	7.5%
Associate Professor	15%	12.9%
Assistant Professor	22%	29.7%
Total	14%	12.2%

Table 2.1.1: Fraction of female faculty at U.S. universities in physics overall in 2010 [18] and in nuclear physics at research universities in 2013 [14]

Although this might be due to the fact that the nuclear physics number are based on more recent data (2013 as compared to 2010 for the physics data from AIP). It certainly suggests a positive trend.

Figure 2.1.8 shows the fraction of female faculty as a function of "year after PhD" both from the 2004 NSAC education report [9] and from the more recent 2013 compilation [14]. It shows that almost all women with PhDs prior to 1975 have retired during the last ten years resulting in the more senior faculty numbers dominated by men. The figure also shows the tremendous increase of the fraction of female faculty hired with PhDs between 2005 and 2010 reaching almost 50%.

Even more impressive is a plot of the absolute numbers of male and female faculty as a function of "year after PhD" as shown in Figure 2.1.9. It demonstrates that the increase of the number of female faculty is not only due to fluctuations of small numbers. Since 1980, there has been a consistent increase in the number of female faculty hired, and although this represents a very positive trend, it will still require a long time for the overall fraction of female faculty to increase. For example, the encouraging number of recent female faculty hires in the 2014 compilation [15] served to increase the overall female representation by only one percentage point, from 12.2% to 13.2%.

While the situation for female faculty is demonstrably improving, the number of faculty from underrepresented minorities continues to be very small. The numbers remain in the single digits which makes it difficult to establish any trends.

There is certainly no evidence of a positive upswing that is visible in the number of female faculty hired in academia recently. This is a largely a pipeline issue, and not unique to nuclear physics. African Americans and Hispanic Americans account for only 1% and 2% of all physics PhDs and 2% and 3% of U.S. physics PhDs, respectively [19].

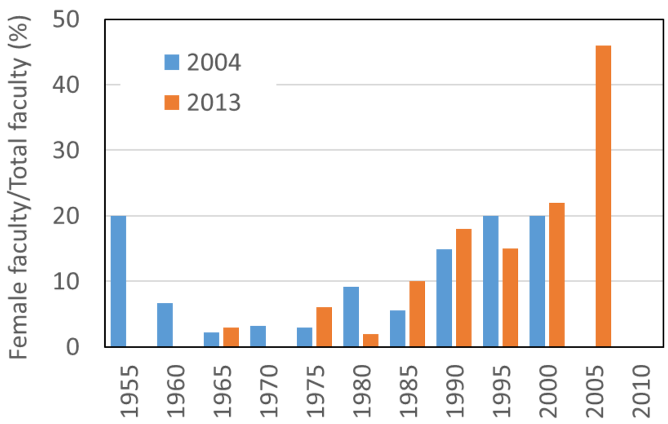
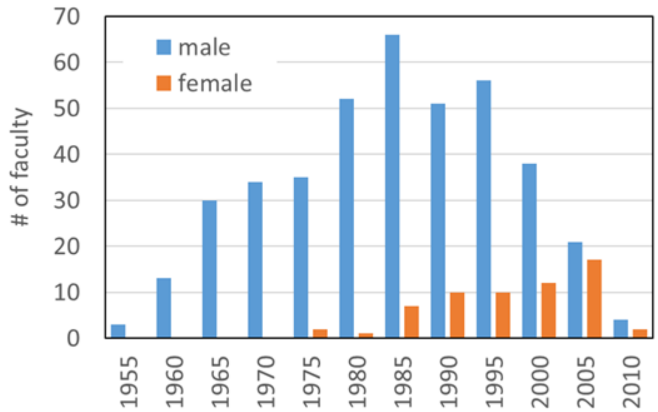


Figure 2.1.8 Fraction of female faculty as a function of "year-of-PhD" from the NSAC education report [9] and the 2013 survey [14].

Figure 2.1.9 Number of female and male faculty as a function of "year-of-PhD" from the 2014 survey [15].



There are many different projects and initiatives whose purpose is to increase the number of underrepresented minorities in physics on all levels in which the nuclear physics community participates. One example is the Fisk-Vanderbilt Master's-to-PhD Bridge Program which is designed to expand opportunities for students from underrepresented minorities to succeed in earning a PhD. [20]. The nuclear physics faculty at Vanderbilt University is directly involved in the program and the first African American nuclear physics student in the program graduated recently. Clearly there is an opportunity for the entire Nuclear Physics community to take more proactive steps to recruit and retain underrepresented minorities in nuclear science disciplines.

NON-PHD WORKFORCE

As mentioned earlier, basic nuclear science research also impacts the education and workforce development of undergraduate and master's students [7]. In the following two sections it will be discussed that fewer graduate and upper-level undergraduate courses are offered because of the decreasing number of nuclear science students.

The available expertise in nuclear techniques and methods can be utilized to educate a broader workforce in applied nuclear science and related fields. Some departments are considering establishment of a professional master's program in nuclear science [21] and/or developing applied nuclear physics laboratories, for example, to train nuclear engineers and radiation workers [22].

RECOMMENDATIONS

A few months prior to the Education and Innovation Town Meeting, DOE charged NSAC to assess the workforce development needs in the Office of Science research disciplines [23]. The main recommendation of the workforce report "… that all stakeholders expand and enhance the training opportunities for undergraduate and graduate students and postdocs" was followed by specific recommendations for the DOE Office of Science [5].

We support the recommendations of the recent NSAC subcommittee on workforce development.

Overall the present trends in the nuclear science workforce situation are rather positive, especially with regard to the substantial number of hires during the last year, including the large fraction of recent female faculty hires. This is due to investments in new facilities and devices, which provides clear evidence to young scientists and the physics, astronomy and chemistry departments in the country that nuclear physics continues to have a bright future. However, in addition to the investments in equipment and infrastructure, the basic research activities, which includes performing, analyzing and interpreting the experiments at these facilities need to be adequately supported.

We recommend continued strong funding of research activities to attract a new generation of students into the field.

About every five years the nuclear science community develops a long range plan. Demographic data are essential to demonstrate the important role of the community in the education of the next generation of scientists for basic nuclear science research as well as for applied fields. Although overall statistics of PhDs awarded is available from various sources [24-26] a more consistent tracking of the career paths is very valuable. The recent NSAC workforce report [5] has already recommended to track the participants of the Science Undergraduate Laboratory Internship (SULI) program.

We recommend that a national effort is coordinated to track the careers of nuclear science PhD, SULI and REU students.

The community needs to seize every opportunity to continue growing the workforce with emphasis on underrepresented groups.

We recommend that the nuclear science community establish stronger relationships with institutions and professional organizations serving underrepresented groups in order to increase research opportunities in nuclear science and associated technologies for students and faculty from traditionally underrepresented backgrounds.

At the Education and Innovation town meeting the attendees endorsed two proposed activities as they are related to the education and training of nuclear scientists.

We endorse the establishment of the proposed FRIB theory center that will serve to educate and nurture the next generation of nuclear scientists.

We endorse the recommendation of the Computational Nuclear Physics Meeting because of the importance of workforce development in scientific computing, and with the opportunity it provides towards training the next generation of interdisciplinary scientists.

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2.2 GRADUATE AND POSTGRADUATE EDUCATION

CURRENT STATUS

Graduate students and postdoctoral researchers are the future of the field. Thus it is important to attract the best and brightest students into the field. More and more, nuclear physics has to compete with traditional subfields pushing the largest (Astrophysics) and the smallest (Particle Physics) frontiers of knowledge and with new emerging exciting new subfields like biophysics.

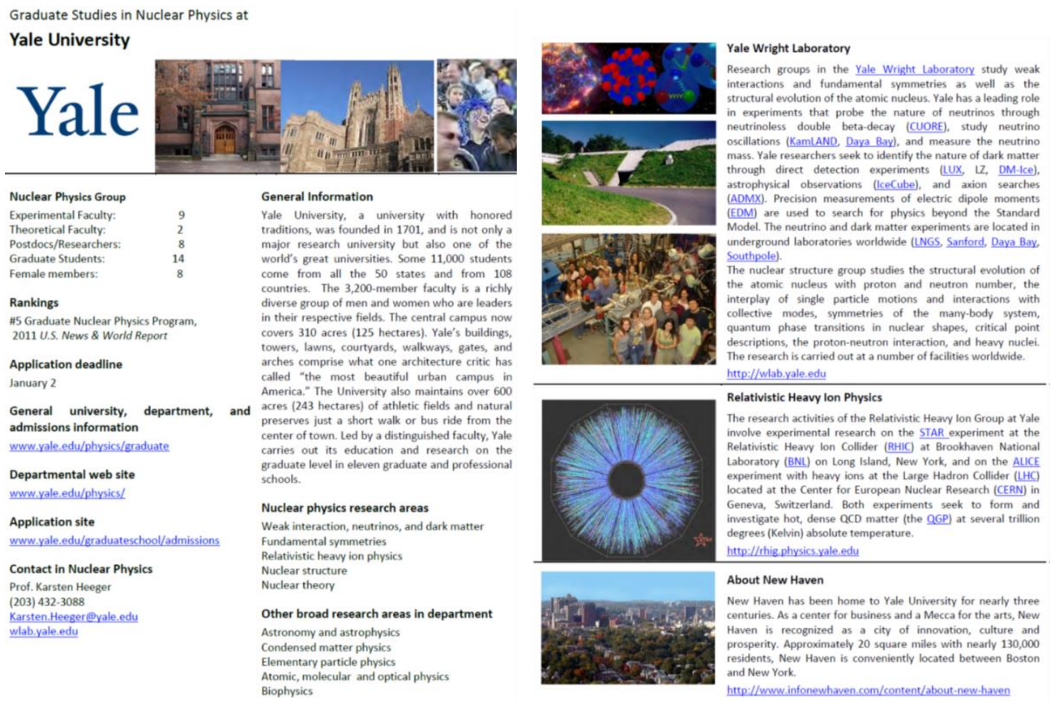
Nuclear physics continues to be one of the fundamental sciences as it is exploring the forces between nucleons and the nature of neutrinos. At the same time the complexity of nuclear phenomena can be compared to nanoscience which Feynman envisioned in his famous "Plenty of Room" lecture in which he stated: "I would like to describe a field, in which little has been done, but in which an enormous amount can be done in principle. This field is not quite the same as the others in that it will not tell us much of fundamental physics (in the sense of, "What are the strange particles?") but ... it might tell us much of great interest about the strange phenomena that occur in complex situations" [1,2].

Many of the most interesting current problems in nuclear physics fall in the category of "strange phenomena that occur in complex situations". The tremendous discovery potential and the excitement of the observation of new phenomena present in all subareas of nuclear physics has to be communicated to students who are considering a career in physics and are looking for the most interesting subfields.

Successful recruiting is only the first step and subsequent retention is at least as important. About 50% of all students entering a doctoral program in physics are not awarded a PhD [3]. The importance of mentoring, guidance, and an overall welcoming environment for the successful completion of a graduate career has recently been reiterated at the APS/AAPT conference on graduate education in physics [4]. Also, students should be made aware of the wide variety of exciting and interesting career opportunities outside of academia that are available to them with a PhD in nuclear physics. Typically about 20% of all physics graduates hold tenure track positions 5-6 years after graduation [5] while the others obtain positions in national laboratories and a wide variety of careers in business and industry (see also section 2.1).

The nuclear physics community has taken a proactive approach to address all the above issues to attract, educate, and train excellent students and prepare them for a successful career.

The most successful recruiting program which is unique to nuclear physics is the Conference Experience for Undergraduate (CEU) program that is described in more detail in section 2.3. In addition, the DNP education committee annually compiles a comprehensive brochure of physics departments offering graduate research programs in nuclear physics. Last year the brochure listed 52 programs [6]. Figure 2.2.1 shows as an example the description of the nuclear physics program at Yale University. The brochure is available on the DNP website and is distributed to the CEU students who value it as an important resource. As one CEU student commented this year: "If you try and search for



Graduate Studies in Nuclear Physics at

Yale University

Yale

Nuclear Physics Group

Experimental Faculty:	9
Theoretical Faculty:	2
Postdocs/Researchers:	8
Graduate Students:	14
Female members:	8

Rankings

#5 Graduate Nuclear Physics Program, 2011 *U.S. News & World Report*

Application deadline

January 2

General university, department, and admissions information

www.yale.edu/physics/graduate

Departmental web site

www.yale.edu/physics/

Application site

www.yale.edu/graduateschool/admissions

Contact in Nuclear Physics

Prof. Karsten Heeger
(203) 432-3088
Karsten.Heeger@yale.edu
wlab.yale.edu

General Information

Yale University, a university with honored traditions, was founded in 1701, and is not only a major research university but also one of the world's great universities. Some 11,000 students come from all the 50 states and from 108 countries. The 3,200-member faculty is a richly diverse group of men and women who are leaders in their respective fields. The central campus now covers 310 acres (125 hectares). Yale's buildings, towers, lawns, courtyards, walkways, gates, and arches comprise what one architecture critic has called "the most beautiful urban campus in America." The University also maintains over 600 acres (243 hectares) of athletic fields and natural preserves just a short walk or bus ride from the center of town. Led by a distinguished faculty, Yale carries out its education and research on the graduate level in eleven graduate and professional schools.

Nuclear physics research areas

Weak interaction, neutrinos, and dark matter
Fundamental symmetries
Relativistic heavy ion physics
Nuclear structure
Nuclear theory

Other broad research areas in department

Astronomy and astrophysics
Condensed matter physics
Elementary particle physics
Atomic, molecular and optical physics
Biophysics

Yale Wright Laboratory

Research groups in the Yale Wright Laboratory study weak interactions and fundamental symmetries as well as the structural evolution of the atomic nucleus. Yale has a leading role in experiments that probe the nature of neutrinos through neutrinoless double beta-decay (CUORE), study neutrino oscillations (KamLAND, Daya Bay), and measure the neutrino mass. Yale researchers seek to identify the nature of dark matter through direct detection experiments (LUX, LZ, DM-Ice), astrophysical observations (IceCube), and axion searches (ADMX). Precision measurements of electric dipole moments (EDM) are used to search for physics beyond the Standard Model. The neutrino and dark matter experiments are located in underground laboratories worldwide (LNGS, Sanford, Daya Bay, Southpole).

The nuclear structure group studies the structural evolution of the atomic nucleus with proton and neutron number, the interplay of single particle motions and interactions with collective modes, symmetries of the many-body system, quantum phase transitions in nuclear shapes, critical point descriptions, the proton-neutron interaction, and heavy nuclei. The research is carried out at a number of facilities worldwide.

http://wlab.yale.edu

Relativistic Heavy Ion Physics

The research activities of the Relativistic Heavy Ion Group at Yale involve experimental research on the STAR experiment at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) on Long Island, New York, and on the ALICE experiment with heavy ions at the Large Hadron Collider (LHC) located at the Center for European Nuclear Research (CERN) in Geneva, Switzerland. Both experiments seek to form and investigate hot, dense QCD matter (the QGP) at several trillion degrees (Kelvin) absolute temperature.

http://rhig.physics.yale.edu

About New Haven

New Haven has been home to Yale University for nearly three centuries. As a center for business and a Mecca for the arts, New Haven is recognized as a city of innovation, culture and prosperity. Approximately 20 square miles with nearly 130,000 residents, New Haven is conveniently located between Boston and New York.

http://www.infonewhaven.com/content/about-new-haven

Figure 2.2.1 Example of a two-page description of the nuclear physics research offered in graduate school included in the Nuclear Physics Graduate Brochure [6].

specifically nuclear physics grad programs on google it is not easy. The only way is to look at every school individually and see if they have a program or not. The graduate school for nuclear physics book is AWESOME. I know that I want to stay in nuclear physics and that book is exactly what I was looking for and very, very helpful" [7].

The DNP also proactively encourages excellent mentoring of graduate students and postdocs. In response to the NSF requirement for a postdoctoral mentoring plan in every grant proposal requesting funding support for postdocs [8] the education committee has compiled a list of best practices for a postdoctoral mentoring plan [9]. In addition, the DNP has offered career workshops at DNP meetings [10], is organizing social events for graduate students and postdocs at the annual fall divisional meetings, and has established a mentoring award for the division [11]. This year the award went to Professor Jorge López from the University of Texas at El Paso for his outstanding record of mentoring students from traditionally underrepresented backgrounds (see Figure 2.2.2) [12].

In anticipation that the NSF will also require a mentoring plan for graduate students [13] several institutions and collaborations have already adapted their postdoctoral mentoring plan to mentoring plans for graduate students [14,15].

Recruiting and educating the best and brightest graduate students requires the appropriate research funding. As already mentioned in the executive summary the level of federal research funding directly impacts the education of the students and post-docs. Any successful utilization of additional funding opportunities outside of nuclear physics will effectively increase the number of graduate students in the field. The recent NSAC report on workforce development has pointed out that the nuclear physics community does not take advantage of these opportunities [16]. Members of the community acted fast and

2014 National Mentoring Award Goes to UTEP Physics

"Jorge López wins the 2014 Mentoring Award of the American Physical Society's Division of Nuclear Physics

The Division of Nuclear Physics (DNP) of the American Physical Society selected Jorge Lopez, Schumaker Professor of Physics, to receive the 2014 Mentoring Award: the recognition is intended to honor DNP members who have had an exceptional impact as mentors of nuclear scientists and students through teaching or research or science-related activities. Through his career Lopez has supervised 24 MS thesis, 1 PhD Dissertation and 35 undergraduate research projects, many of the projects have been in nuclear physics.

In Lopez's case the citation reads:
"For his outstanding record of mentoring undergraduate and graduate students in nuclear physics research, particularly students from traditionally under-represented backgrounds, many of whom have continued their studies to receive advanced degrees in nuclear physics, and for his leadership in the National Society of Hispanic Physicists."

The award and certificate will be issued at the upcoming DNP Business Meeting at the 4th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, October 7-11, 2014 in Kona, Hawaii.

Figure 2.2.2 The 2014 mentoring award for Professor Jorge López was highlighted on the University of Texas at El Paso website [12].

wrote an overview and guide to available National Fellowships [17] which was then immediately posted prominently on the DNP home page. This example shows again the proactive involvement of the community and the fast and efficient response of the DNP.

The relatively small fraction of graduate students pursuing a degree in nuclear physics makes it difficult for departments to offer advanced specialized courses in a timely fashion. The nuclear physics community has approached this issue some time ago with the establishment of the National Nuclear Physics Summer Schools (NNPSS) in 1987 [18].

However, since 1987, nuclear physics has become more focused on separate subtopics requiring even more specialized courses for even fewer students. Furthermore, students interested in these topics are typically distributed over several different institutions. A variety of approaches are currently being implemented in order to educate the students efficiently.

At MIT the need for fast specialized introduction of advanced material to be offered to only 1-2 new graduate students per year is being solved by using a MOOC (Massive Online Open Courses) style approach. MOOCs were developed to bring lectures to a large, global audience, however, they can also be used to teach a small number of students again and again. As a first attempt a course on Effective Field Theory is being offered for free worldwide online (see Figure 2.2.3) [19].

The low-energy nuclear physics community has formed the TALENT (Training in Advanced Low Energy Nuclear Theory) educational initiative [20] to provide advanced and comprehensive training to graduate students and young researchers. The goal is to develop a broad curriculum for cutting-edge theory to understand nuclei and nuclear reactions and astrophysics, and to build strong connections between universities and research laboratories and institutes worldwide on educational developments in nuclear physics. By the end of 2015, eight TALENT courses will have been offered by world-leading experts, each with 20-30 participants for an intensive three-week course featuring active learning and student projects. Future plans include developing a repository of consistent and well-linked teaching materials that exploit advances in pedagogy and technological tools, and coordinating TALENT in the US with the FRIB Theory Center.

In a different approach the relativistic heavy ion community is developing the School of Heavy Ion Physics (SHIP) [21]. It is based on a new concept which does not rely on online versions of traditional graduate level courses and a linear structure of lectures. Instead, short colloquium/seminar level lectures and more specialized micro lectures will

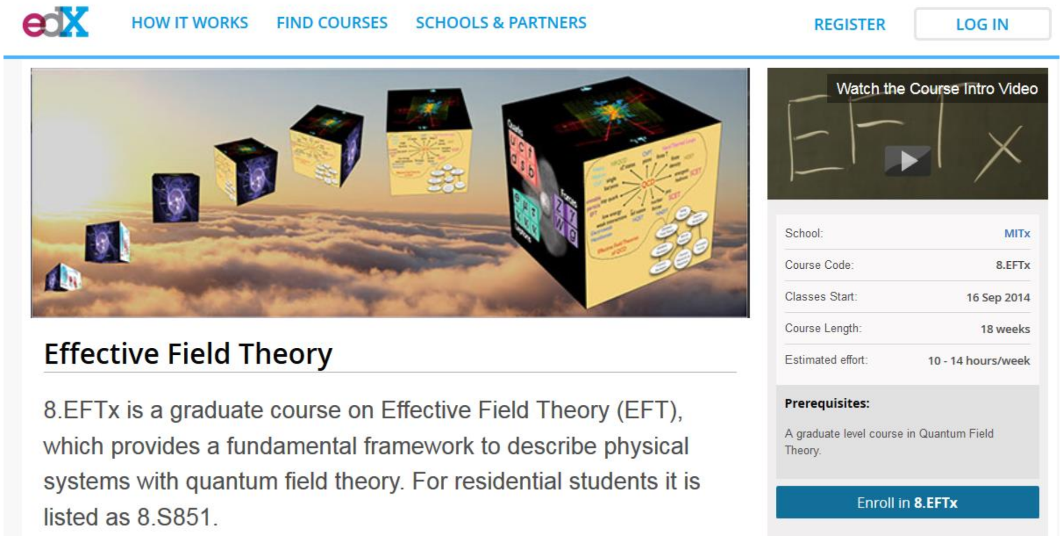


Figure 2.2.3 MIT is currently offering an online course in Effective Field Theory [19].

be augmented by a sequence of video clips, concept questions, and frameworks for hands-on exercises.

Although the need for more and more specialized courses increases, solving the emerging problems in nuclear physics requires significant collaborations among the specialists within, as well as outside of nuclear physics. The recent formation of topical collaborations addresses this issue. Within these collaborations graduate students and postdocs get the opportunity to interact with and learn from the experts of different subfields working towards a common goal.

In 2010, three topical collaborations were established: JET (Jet and Electromagnetic Tomography of Extreme Phases of Matter in Heavy-ion Collisions) [22], TORUS (Theory of Reactions for Unstable iSotopes) [23] and Neutrinos and Nucleosynthesis in Hot and Dense Matter [24]. All three actively teach students and postdocs by organizing workshops, summer schools and collaboration meetings.

RECOMMENDATIONS

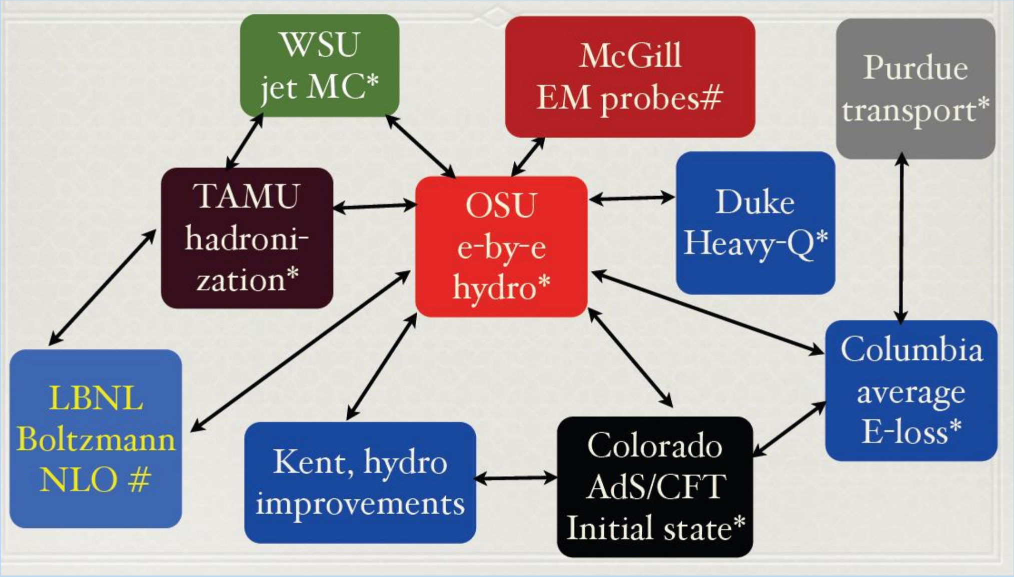
Undergraduate students contemplating graduate school in physics typically rely on research mentors for advice. The success of the CEU program as an effective recruiting tool is based on this relation between student and mentor. It offers a forum where the student and the mentor have the opportunity to meet and interact with professors and researchers from other institutions and discuss different graduate school opportunities in nuclear science. The students also collect online information from one of the most comprehensive databases for graduate programs in physics: the AIP website gradschoolshopper.com [25]. Other important online resources for students are the websites of the individual departments describing the research programs. Nuclear physics research programs have to be prominently visible on these sites.

Topical Collaboration: JET

The topical collaboration on Jet and Electromagnetic Tomography of extreme phases of matter in heavy-ion collisions (JET) attempts to understand the interactions of quasi-free quarks, anti-quarks and gluons at very high temperature [22]. This quark-gluon plasma or de-confined phase exists for only a very short time (~10^{-23}s). It is important to understand the various mechanisms forming the quark-gluon plasma (initial state and pre-equilibrium phase) and the decay stages (hadronization, freeze-out and hadronic phase). This involves the work of different groups concentrating on the initial state physics, relativistic viscous fluid dynamical simulations, perturbative QCD based Jet modification, hadronization of medium and jet, and electromagnetic emission from collisions.

Central to the mission of JET is the spreading of knowhow beyond the JET member institutions. JET holds annual 3 day summer schools and a collaboration meeting. About 20-30 students per year attend these meetings where lecturers are drawn from world experts both within JET and beyond.

In addition, JET holds 1-2 workshops per year on frontier topics in heavy-ion collisions. About 10-15 students participate where they get first-hand experience of theory and experimental debates [25].



Schematic diagram of the distributed effort and interaction among the different groups [25].

The relevance and visibility of nuclear science depends to a certain extent on statistical data. Thus it is important for the future of the field that the numbers of completed PhD theses in nuclear science per year are correctly accounted for in the relevant databases.

We recommend that departments should include their profile on the AIP list of grad schools (gradschoolshopper.com) and list nuclear physics as a distinct identifiable research area on the department website. Professors should ensure that Master's and Ph.D. theses are categorized and reported with the appropriate subject and keywords.

Nuclear physics is underrepresented in the number of national fellowships awarded to students within the field. Nuclear physics has many outstanding students who qualify for these awards. These resources for student support should be utilized more aggressively independent of the funding support for research within the field.

We recommend that research advisors actively encourage excellent students to apply for competitive fellowships.

Nuclear physicists have traditionally been innovative leaders in the education of students at all levels by developing new ideas and approaches. There are currently several initiatives to teach topics of specialized interest timely and effectively to a relatively small number of students.

We recommend to continue to explore new emerging trends in educational technology, in particular frameworks for online education in nuclear science as a component to enhance graduate and postgraduate courses.

Topical theory collaborations have proven to be a successful model for educating graduate students and postdocs in theoretical research.

We recommend the continued strong support for topical collaborations.

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2.3 UNDERGRADUATE EDUCATION

CURRENT STATUS

Exposing undergraduate students to nuclear physics research is the most effective way to attract and retain the best students, and to positively influence their decision to continue their research into graduate school. The last long range plan already emphasized undergraduate research as one of the priorities related to education and outreach: "the enhancement of existing programs and the inception of new ones that address the goals of increasing the visibility of nuclear science in undergraduate education and the involvement of undergraduates in research;..." [1]. This recommendation was based on the community education white paper prepared for the long range plan which stated as its highest priority: "The nuclear science community should increase its involvement and visibility in undergraduate education and research, so as to increase the number of nuclear science Ph.D.'s and the number of scientists, engineers and physics teachers exposed to nuclear science" [2].

More recently the American Physical Society published a statement to call "upon the nation's four-year colleges and universities and their physics and astronomy departments to provide or facilitate access to research experiences for all undergraduate physics and astronomy majors" [3].

In the APS statement, the importance of the skills learned during research including "problem definition, project design, open-ended problem solving, use of modern instruments and techniques, data collection and analysis, analytical and computational modeling, and communication of evidence-based technical arguments" are identified as being beneficial not only for a career in academia but also more generally for other careers. It also emphasizes that undergraduate research experiences increase retention of students in STEM disciplines.

The Nuclear Physics community has recognized the importance of early research experience for a long time. Already in 1983 the NSAC Long Range Plan stated as the first recommendation with regards to manpower and training: "Programs which involve undergraduates in nuclear science research are extremely important in attracting students to the field... efforts should be made to strengthen and expand these... if necessary with specific funding from the agencies" [4]. When the NSF (re)instituted the Research Experience for Undergraduates (REU) programs in 1987, half of the first successful proposals were led by nuclear physicists. The Nuclear Physics community continues to take advantage of the REU and the DOE sponsored Science Undergraduate Laboratory Internships (SULI) program. For example, out of 48 sites posted on the NSF physics REU site which specify subfield research options, 19 (40% of the programs) list nuclear physics as an option [5]. However, it should be mentioned that the REU program at three major research universities with nuclear physics research groups do not include nuclear physics.

The crucial and important impact that a research experience has at the undergraduate level in nuclear physics is evidenced by the MoNA (Modular Neutron Array) collaboration, which consists of a partnership of nine undergraduate institutions, one HBCU, and the National Superconducting Cyclotron Laboratory (NSCL) at Michigan

State University studying neutron-rich unstable nuclei. Over the last twelve years more than 150 undergraduate students worked on research projects from assembling and testing detectors to participating in experiments and analyzing data. Because of the composition of the collaboration, almost 80% of the students come from small liberal arts colleges where they often do not have the opportunity to gain significant research experience.

Figure 2.3.1 demonstrates the impact of research experience on students' future career decisions. It compares data from an AIP survey [6] for students with a BS/BA degree from Bachelor's granting institutions with data for MoNA students. The figure shows that a significantly larger fraction of MoNA students (69%) chose to continue on to the pursuit of an advanced degree than students graduating from a Bachelor's granting institution (50%). It should be noted that students from Bachelor's granting institutions represent about one-third of all students from U.S. colleges and universities entering graduate school in physics.

Additional evidence that the research experience influences a student's career decision is that fact that the fraction of MoNA students entering graduate school who chose to study nuclear physics (13%) is significantly larger than the fraction of nuclear physics graduate students in the U.S. overall (~5%, average number of PhDs from 2000 – 2012, see Figure 2.1.2).

The nuclear physics community has been cognizant of this important fact for a long time and has benefited from the concept proposed by Warren Rogers to give undergraduate students the opportunity to participate in the annual DNP meeting. This Conference Experience for Undergraduates (CEU) program [11] which was first organized in 1998 has been very successful. Figure 2.3.2 shows the number of undergraduate students participating in the program from 1998 – 2014 [12]. The attendance has essentially doubled over 17 years, peaking last year at over 160 students. To date over 1600 undergraduate students have participated.

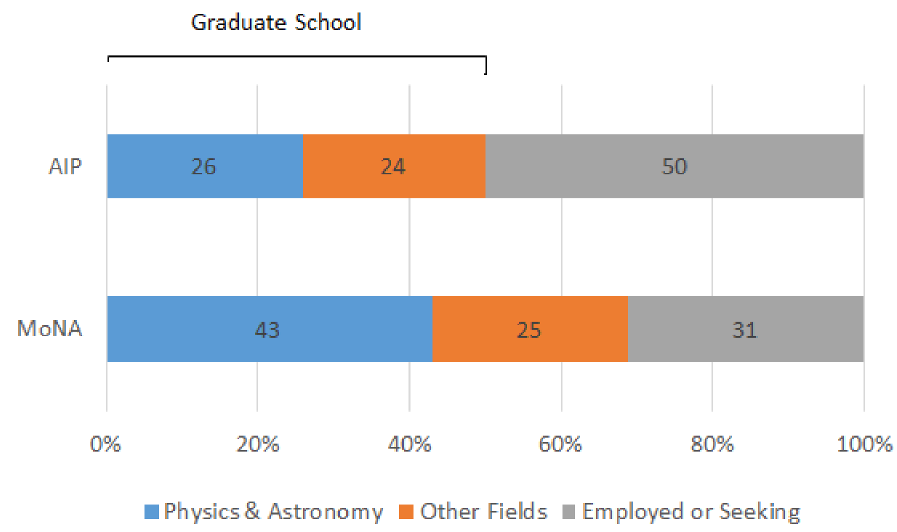


Figure 2.3.1 Career choices of BS/BA graduates from bachelor's granting institutions in the U.S. from an AIP survey [6] and from the MoNA collaboration. The AIP data is from 1974 respondents from 2011 and 2012, and the MoNA data is based on 97 students from 2002 – 2014.

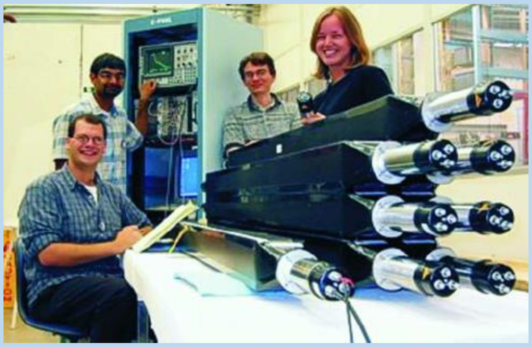
Mustafa Rajabali

Mustafa Rajabali was one of the first undergraduate students in the MoNA collaboration. In 2002, a student at Concordia College in Moorhead, Minnesota he joined Professor Bryan Luther in construction of the first layer of 16 scintillation detectors of the Modular Neutron Array, which had been funded by an NSF MRI grant. He participated in the first experiment at the NSCL with a subset of the detector and presented his research at the fifth CEU program at the 2002 DNP meeting in East Lansing, Michigan [7].

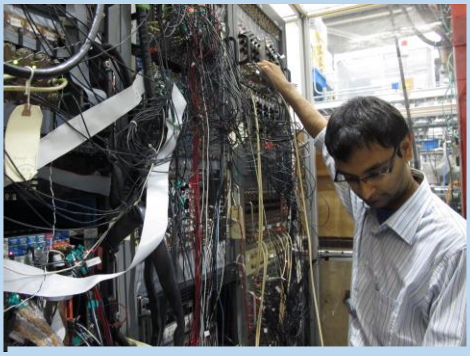
After receiving his B.A. in physics, mathematics, and chemistry in 2003 he entered the Master's program at North Dakota State University where he received his M.S. in condensed matter physics in 2005. He then decided to return to nuclear physics and received his Ph.D. from the University of Tennessee in 2009 working with Professor Robert Grzywacz. His thesis topic was β-decay, β-delayed neutron emission and isomer studies around ^{78}Ni [8].

After completing two postdoc positions, one at the University of Leuven in Belgium (2009-2012) and followed by one at TRIUMF (2012-2014), he recently joined the faculty at Tennessee Tech as an Assistant Professor.

Professor Rajabali's research interest is low energy nuclear physics (the study of nuclear structure via α,β, and γ decay, laser spectroscopy and detector development for radiation detection) and interdisciplinary science (application of radiation detection methods for research in geography, biology and environmental science) [9].



Assemby and testing of the first MoNA detectors. Undergraduate students Ramsey Turner (left), Mustafa Rajabali (second from left) and Melanie Evanger (right) and Professor Bryan Luther (second from right) from Concordia College [10].



Assistant Professor Mustafa Rajabali, Department of Physics, Tennessee Technological University [9]

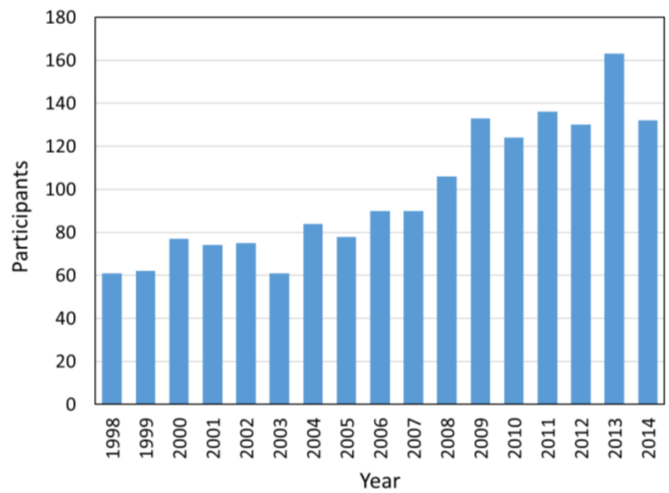


Figure 2.3.2 Number of undergraduate students participating in the DNP CEU program [12].

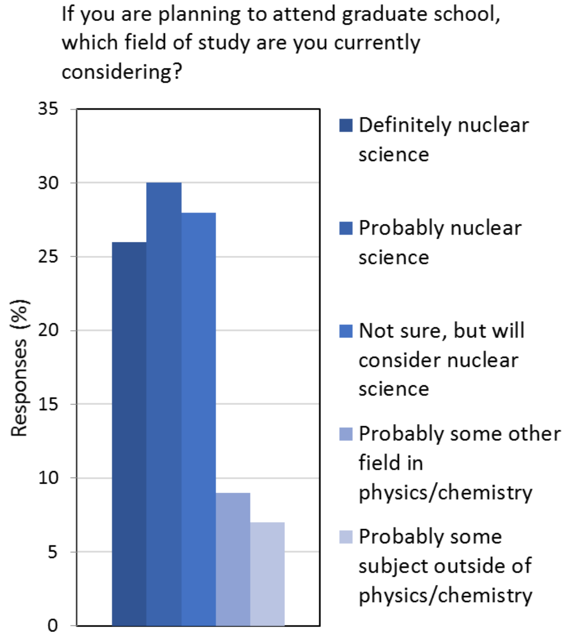
The CEU program was designed specifically to enable student researchers to bring their efforts to full fruition by presenting their work to the professional nuclear science community at a national conference. The CEU provides the logical capstone experience for their research projects, and in the process exposes them firsthand to the excitement of the field and the human face of the nuclear science community.

Funding for the conference has been provided by the National Science Foundation and the Department of Energy (through the national accelerator laboratories) and the APS Division of Nuclear Physics. The CEU draws applications from students from around the country and abroad. Their application materials are reviewed by an independent review committee, and travel and lodging grants are awarded based on project merit. Students who do not receive awards are often able to participate based on assistance from their research advisers or home institutions. For most, participation in the DNP meeting represents their first professional conference experience and the first opportunity to present their research to a broader professional audience in nuclear science.

Several specific CEU activities are organized for the students as part of their conference experience, including two nuclear physics seminars directed at an advanced undergraduate level on topics of broad and current interest in the field of nuclear science, a social event where they also have an opportunity to meet with several members in DNP leadership, a research poster session that is probably the best-attended event following the plenary session talks, and a graduate school information fair where students can learn about a number of graduate school opportunities in nuclear science. A presentation on graduate school application advice and tips has also been added in recent years.

Survey and anecdotal data indicate several benefits of CEU participation, including an increased interest in the field of nuclear science and in the prospect of attending graduate school in physics. Figure 2.3.3 shows the survey result from the most recent CEU program [12]. Students discover that scientists are genuinely interested in their research, that is, that their research contribution to nuclear science is valued and highly relevant to the field as a whole. They meet peers, graduate students, and established scientists who share a common interest and bond in physics and research, and many students catch an inspiring vision of a future in nuclear science. They see first-hand how fundamental communication and sharing of ideas occurs among professional scientists. They have a unique opportunity

Figure 2.3.3 CEU survey result [12]



to discuss graduate school opportunities with scientists from several top institutions and laboratories. Each of these benefits serves to strengthen retention of talented students in nuclear science. Finally, the entire nuclear science community benefits from the energy and excitement these bright young scientists bring to the meeting.

The anecdotal data are also supported by a follow-up study which collected the current career information of the cohort of the first five years (1998 – 2002) from an online search [18]. Figure 2.3.4 shows the percentage of students selecting nuclear physics in graduate school for students who received their PhD from 2000 – 2012 [18], with the same data for MoNA and CEU students from 1998 – 2002. The figure clearly demonstrates that students participating in the CEU program select nuclear physics at a much higher percentage rate than the general student population. With similar results for the MoNA student data shown in Figure 2.3.1, the study also demonstrated that the CEU students enter graduate school at a higher rate. It should be mentioned that these CEU students are very talented academically, as about 30% of the CEU students in the study entering graduate school enrolled in Ivy League or equivalent schools (Caltech, Chicago, MIT, etc.).

The smaller fraction of graduate students selecting nuclear physics (see Figure 2.1.2) results in a reduction of nuclear physics classes and labs offered at the undergraduate level [2]. The community has begun to address this challenge by adopting several different approaches. The University of Rochester developed a broader lab for nuclear science and technology for nuclear physics, chemistry and engineering students [20]. A nuclear physics summer school for basic nuclear physics has been funded through an NSF CAREER grant at Michigan State University [21], and efforts are under way to develop modules online that can be shared among institutions [22].

Anne Sickles

Anne Sickles participated in the second and third Conference Experience for Undergraduates (CEU) programs at the DNP meetings in Asilomar, CA and Williamsburg, VA, in 1999 and 2000, respectively. At the time she was an undergraduate student at Gonzaga University and she presented posters on her summer research at Michigan State University and the University of Michigan. In 1999 she worked with Professor Gary Westfall and presented a CEU poster entitled “The Search for the Quark Gluon Plasma” [13]. In 2000 she worked with Professor Fred Becchetti and the BIGSOL collaboration on the “Velocities of Neutron-Rich Fragments of ^{136}Xe on ^{nat}C at E/A = 30MeV/u collected at 1.36 T-m and $\theta_{lab} \geq \theta_{grazing}$“ [14].

After receiving her bachelor's degree in physics in 2001 she went to graduate school at Stony Brook University where she received her Ph.D. in physics in 2005. She performed her research with Professor Barbara Jacak and the PHENIX Collaboration on Azimuthal correlation and conditional yield measurements at center of mass energies = 200 GeV in Au+Au, d+Au and p+p collisions at RHIC [15].

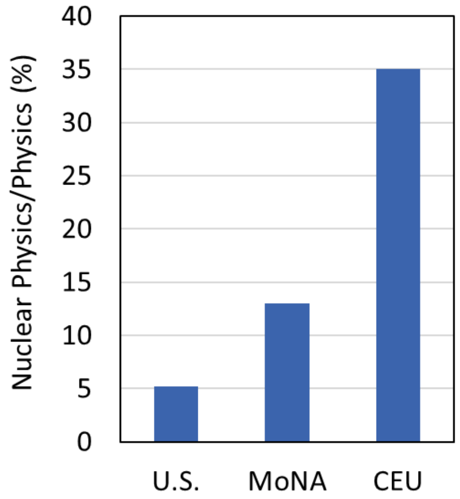
She was a postdoctoral researcher at Brookhaven National Laboratory from 2005 to 2009. In 2009 she joined the scientific staff of Brookhaven, first as an Assistant Physicist and then Associate Physicist (2011). She then joined the faculty in the Department of Physics at the University of Illinois as an assistant professor in 2014.

Professor Sickles' research is in the field of relativistic heavy ion collisions. She is a member of the ATLAS Collaboration at the Large Hadron Collider at CERN and the PHENIX Experiment at the Relativistic Heavy Ion Collider at Brookhaven [16].

CEU/DNP 2000 Graduate school information session; Anne Sickles and Prof. Gene Sprouse (SUNY, Stony Brook) [17].

Assistant Professor Anne Sickles, Department of Physics, University of Illinois [16].

Figure 2.3.4 Fraction of graduate students in Nuclear Physics. The U.S. fraction corresponds to the average number of PhDs from 2000 – 2012 [19].



The same challenge existed for a considerable time for the nuclear chemistry community. As the 2012 National Academy of Sciences Study concluded "In closing, based on the state of research funding and the academic pipeline, the committee is not very optimistic about the projected state of nuclear and radiochemistry expertise. If trends in funding and academic support continue (including reliance on personnel without expertise in nuclear and radiochemistry and increasing dependence on the use of on-the-job training to cover shortfalls in properly trained personnel), the projected supply of U.S. nuclear and radiochemistry expertise will barely meet basic demands for at least the next 5 years. The small size of the expertise pool makes it fragile and vulnerable; it should be supported in a more coordinated and strategic manner than it is currently. Furthermore, should there be major funding cuts, policy changes, or world events, the U.S. supply of nuclear and radiochemistry expertise will be inadequate" [23].

To address the lack of undergraduate student exposure to the fields of nuclear and radiochemistry at the majority of academic institutions in the U.S., the American Chemical Society together with funding from the Department of Energy instituted the National Nuclear Chemistry Summer Schools (NCSS). The NCSS is an intensive 6-week program designed to introduce nuclear and radiochemical concepts through lecture and laboratory experiments to outstanding upper level science and engineering majors and to stimulate their interest to pursue graduate studies in the field. Since they were first introduced in 1984, the NCSS have successfully introduced 651 of this nation's best and brightest to nuclear and radiochemistry. Nearly 20% of all NCSS participants have gone on to pursue careers in the nuclear sciences. The impact and importance of the NCSS is highlighted by the fact that approximately half of the 15 to 20 nuclear chemistry and radiochemistry Ph.D. degrees now awarded annually in the U.S. are to individuals who were introduced to the field through the NCSS.

RECOMMENDATIONS

In recent years the NCSS have provided essentially the only opportunity for chemistry students to be exposed to and involved in nuclear chemistry. The nuclear science community is very disappointed in the lack of funding in the 2015 budget for the NCSS and is concerned about the future education of nuclear chemists.

We recommend that the funding for the Nuclear Chemistry Summer Schools be restored, and further that it continue receiving support in the future.

It is by now clear that undergraduate student exposure to research opportunities provides them strong encouragement and incentive to continue their studies into graduate school. Opportunities such as research assistant positions or research participation for credit during the semester, as well as summer programs like the NSF Research Experience for Undergraduates (REU) and the DOE Science Undergraduate Laboratory Internships (SULI) have all proven to be extremely beneficial to student motivation and future graduate education and career planning. The latter are especially valuable for students from smaller institutions where students have only limited access to hands-on research.

We recommend strong support by the agencies for undergraduate research. Increased opportunities for collaborations between faculty and students from primarily undergraduate institutions and groups at research institutions should be facilitated.

The CEU program has been a very successful program serving over 1600 students over the last 17 years. It provides a great capstone experience for the undergraduate participants' research experiences. It represents a very unique program within the APS and attracts a large number of excellent graduate students into nuclear physics. However, its organization presently relies heavily on the motivation and energy of a single person, which does not represent a sustainable operation model going forward. It is therefore critical that the program be institutionalized within the DNP.

We strongly encourage the agencies to continue funding of the CEU program. For long term stability, the program should be administered by the DNP using a model similar to the ACS NUCL administration of the Nuclear Chemistry Summer Schools.

Prior to any experimental nuclear research experiences, students should learn some basic lab skills in nuclear science. However, as fewer colleges and universities offer any advanced lab courses that include a nuclear physics component, a larger fraction of the students do not gain these skills. Also the number of nuclear physics courses available at the undergraduate level is decreasing. Innovative approaches to include nuclear physics in the undergraduate curriculum should be pursued. New emerging trends in educational technology, in particular frameworks for online education are being used as more and more become available.

We recommend an increase in the number of undergraduate level nuclear physics hands-on summer schools and labs, as well as in the development of online material as a component for enhancing undergraduate courses with nuclear physics material.

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2.4 K-12 AND OUTREACH

CURRENT STATUS

The need for a strong scientific workforce, discussed in section 2.1, is not unique to nuclear physics. The future health of many scientific fields, and the nuclear science enterprise in particular, depends on the continued flow of bright, young professionals into the field at all levels. Furthermore, these young professionals must better represent the diversity of our society in the future to ensure the field is reaching and retaining the best minds for continued research success and positive growth.

Diversifying the workforce in nuclear science in order to meet these goals requires that the pipeline be broadened. It is still important to encourage undergraduate students to enter the field because the number of students earning bachelor's degrees in physics has not kept pace with the explosion of degrees granted in STEM fields since 1970. While the number of degrees in all STEM fields more than doubled by 2012 the number of physics degrees increased by only 30 percent [1]. Further, physics trails all STEM disciplines in the percentage of degrees obtained by underrepresented minorities [2].

To attract the absolute best and the brightest students to the field, it is critical that nuclear science programs reach beyond college campuses and into middle and upper secondary schools serving underrepresented groups, ensuring that promising students are aware of the exciting possibilities made possible by a career in physics and encouraging students to study science and math in high school and college. This is a long-term effort that can provide long-term rewards to the students and to the field, and these efforts must be valued, encouraged and sustained.

It is equally important that members of the general public recognize and value both basic and applied research in nuclear science. Many members of the nuclear community recognize these needs and are working to address them locally and regionally through outreach efforts to the public and to K-12 educators and students. There are many excellent examples of a wide range of activities to educate the public and excite K-12 students about nuclear science.

For example, the Nuclear Science Wall Chart, which was developed by the Contemporary Physics Education Project at Lawrence Berkeley National Lab [3], has been widely distributed and is recognizable as related to the field of nuclear science by the general population. For example, it could be seen in the background in the cult film "Donnie Darko" (Figure 2.4.1) [4].

The nuclear science community has also taken advantage of its powerful accelerators and impressive experimental equipment for outreach activities. Capitalizing on these invaluable assets by showcasing them at open houses and tours that typically draw large audiences provide visual confirmation of the technical complexity and large scale of the field. At this year’s open houses alone, more than 5,500 visitors toured Jefferson Lab (with more than 2,000 touring the accelerator facility itself), about 1,300 visitors toured the Relativistic Heavy Ion Collider at Brookhaven National Lab, and Neutrino Day at the Sanford Underground Research Facility drew more than 1,000 visitors. In total, about

Figure 2.4.1 The nuclear chart can be seen in a scene of the cult film "Donnie Darko" [4].

11,000 people visit RHIC, Jefferson Lab and the National Superconducting Cyclotron Laboratory on scheduled tours every year.

In addition to facility tours, many activities that do not necessarily rely on accelerators and large laboratories are being organized to engage K-12 students and the general public. Examples include public lecture events, such as the Happy Hour at Yale, the Science Café at Brookhaven National Lab, and Saturday Morning Physics at Texas A&M University. Activities specifically engaging children are the Art 2 Science program (Joint Institute for Nuclear Astrophysics), merit badge events for Boy and Girl Scouts (University of Notre Dame and Lawrence Berkeley National Lab), and a Physics Olympiad (Richmond University).

Other events are specifically designed to increase the participation of underrepresented minorities, such as the Nuclear Science Lab Field Trips at the University of Notre Dame and Michigan State University and the BEAMS (Becoming Enthusiastic About Math and Science) program at Jefferson Lab.

The breadth and variety of current outreach activities is demonstrated by the 50 examples presented in Appendix D. These examples will also be available for the entire community as a separate document [5].

Social media sites also provide a platform for the nuclear science community to engage the general public. In order to communicate effectively, it is important to capitalize on

Figure 2.4.2 Participants at the 2014 Jefferson Lab open house [6]

Innovative Outreach Activities

The nuclear physics community has traditionally provided national leadership through its work with K-12 students, both at its major laboratories and through smaller laboratories and even through the efforts of individual nuclear physicists.

In order to stress the importance of outreach for the overall community, it is important to engage students as early as possible. For example, as part of the Research Experience for Undergraduates program at Texas A&M University, undergraduate students put together hands-on activities for the monthly "First Friday" event in downtown Bryan, where people fill the streets to enjoy arts, music and science [7].

Another great approach is to involve other departments in efforts to promote nuclear science. For example, Prof. Agnes Mocsy of the Pratt Institute involves students from computer science, fine arts, film, photography, illustration and architecture in science projects related to the Relativistic Heavy Ion Collider at Brookhaven National Lab [8]. In collaboration with the Games for Entertainment and Learning Lab at the National Superconducting Cyclotron Laboratory, Michigan State University is currently developing a video game based on producing radioactive isotopes. The project was funded by an APS outreach grant [9].

"Street Physics" at Texas A&M University, where REU students present hands-on science activities [10].

Artist Sarah Szabo with pieces from her "Glamorous Gluon" collection [11].

these existing and popular sites to reach a science-interested audience. Outreach coordinators at Brookhaven National Lab, Jefferson Lab, Lawrence Berkeley National Lab, the National Superconducting Cyclotron Laboratory and the Joint Institute for Nuclear Astrophysics, for example, have all used social media sites, such as YouTube, Facebook, Twitter, Pinterest, etc., to engage the general public, school teachers and students. These sites provide the opportunity for interactions that go beyond just the posting of information and can lead to an open dialog with the public about the research activities that these organizations carry out. For others in the tech-savvy public who want to learn more about nuclear physics research, there is even an interactive chart of nuclei that is now available as a mobile app [12].

Finally, a very important target audience for outreach activities is policymakers. Again, the nuclear physics community has taken a very proactive approach. The APS Division of Nuclear Physics instituted a funding committee that organizes congressional visits. Many users from all subfields participate in the annual Nuclear Physics Day on the Hill. In addition, all nuclear physics user facilities are members of the National User Facility Organization (NUFO) and take part in the annual user science exhibition for Congress [13]. In addition, the website smashingmatters.org offers an easy way for concerned citizens to contact their Senators and Representatives and send a letter asking for funding support for basic science [14].

RECOMMENDATIONS

Outreach and dissemination of results to a broad audience are an integral part of a nuclear physicist's job. Students must be introduced to the idea early in their studies and need experience successfully communicating with audiences outside their immediate field. They must be educated about the importance of these activities for both their own careers and the continued health of the field. As most of the basic nuclear physics research is federally funded, it is imperative that research results are well communicated to policymakers and the tax-paying public.

We recommend that workshops on communicating nuclear science to non-experts be offered for undergraduate students, graduate students and postdocs at DNP/APS meetings, in order to better their presentation skills. Avenues should be explored to disseminate important scientific results more consistently to the funding agencies and the general news media.

Appendix D highlights many excellent outreach programs within the nuclear physics community. In order to avoid duplication of effort and better communicate and coordinate these efforts, a means of sharing resources needs to be found to make outreach efforts more efficient and effective. A compilation and description of programs on the national level would be beneficial.

We recommend that the DNP should facilitate a networking organization of community members working in outreach and education. This will enable participants to share their activities, learn from each other, and find points of connection that could lead to joint grant proposals in the future. A website for

shared resources should be part of the effort. External funding avenues, both government and private, should be explored to sustain these activities.

The coordination of outreach activities should not be limited to the nuclear science community. Programs that reach out to the general public and K-12 do not have to be limited to nuclear physics topics and should be integrated and coordinated within broader science outreach activities.

We recommend that nuclear science community outreach efforts should be coordinated with other outreach organizations focusing on STEM activities. Organizations for underrepresented minorities should also be included in these efforts to optimize the impact in these communities.

The Nuclear Science Wall Chart has been an extremely effective way to communicate nuclear science to a broad audience. However, it was produced in 2004, and nuclear science has made significant advances since then. The most recent discoveries are not included in the present version of the chart.

We recommend that the Nuclear Science Wall Chart should be updated and widely disseminated for use.

Outreach activities require a lot of effort, time and resources from scientists who are mostly driven by excitement and enthusiasm for their own research. These efforts are in general not federally funded and, in many cases, are not supported at all. Outreach efforts are an important service to the nuclear science community and should be better appreciated.

We recommend that the nuclear science community explore options to recognize and reward significant outreach activities.

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3 INNOVATION

Applications of nuclear science have figured prominently in previous long-range reports. There are many reasons for this emphasis, not to detract from the tremendous advances in fundamental nuclear science research, but to help communicate the importance of this research to the funding agencies and to the broader community which must support it. Therefore, the Education & Innovation Town Meeting brought together nuclear scientists to highlight their recent innovations in the areas of: Defense and Security, Energy and Climate, Health and Medicine, and Art, Forensics and other Applications. These broad categories were selected from the APS brochure "By the Dawn's Early Light" prepared for the annual Nuclear Physics Day on the Hill event, where the most visible innovations of nuclear physics and their impacts on society were presented to elected officials and their staffers in Washington, DC [1].

At the town meeting, it was possible to discern increased activity, excitement and interest in several innovative nuclear science applications in each of the established categories. There was a definite desire among participants to not only provide motivating examples to include as "compelling applications of nuclear science boxes" in the white paper, but to make some observations and recommendations about all the roles innovations play in the nuclear science community. The connection between innovative applications of nuclear science and their role in education and attracting students into the field was already mentioned earlier, but cannot be overstated. It is the societal impacts of nuclear science that most students encounter long before their formal education in nuclear science commences. It is from our self-promotion of these societal advances that future students will become aware of nuclear science as a potential career path, and that funding agencies will have continued justification for funding research into basic nuclear science.

The report entitled "Nuclear Science: Enhancing American Competitiveness through Basic Research" [2], written in preparation of the 2007 long range plan, tied applications of nuclear science to American economic competitiveness. This report provided a list of existing nuclear physics applications with impact on society, and multiple lists, sidebars and tables of potential new applications. Most of the topics summarized as successful "spin-off" applications of nuclear science in this earlier report are still relevant today. The participants of the Education and Innovation Town Meeting simply expanded further on the impressive list of societal contributions that nuclear science, and nuclear scientists have made. Table 3.1 lists some of the best-known examples of nuclear science innovations with societal impact, compiled from previously published reports [1-4] as well as contributions to the town meeting.

Overall, there was broad recognition that developing innovative applications of nuclear science has a significant impact on the discipline as a whole and society itself. In the following sections, some specific examples in each of the defined categories of the town meeting will be presented in language accessible to any reader. They are not the only examples possible in each category, but they represent a selection of compelling cases which highlight the wide array of innovative nuclear science applications.

Table 3.1 Table of Nuclear Science Innovations and Applications with Societal Impact

Defense and Security
Stockpile Stewardship
Advanced simulation tools, computational applications of "big data"
International arms control and non-proliferation treaty verification efforts
Nuclear forensics and forensic dosimetry
Homeland security: Airport safety
Homeland security: Cargo inspection and interrogation
Energy and Climate
Nuclear reactors for power
Accelerator advances for reactor safety
Spent fuel transmutation
Nuclear batteries: Radionuclides for space exploration
Well logging for oil and gas exploration
Climate-change monitoring via Accelerator Mass Spectrometry
Pollution control: smokestack ion beam scrubbers
Groundwater monitoring with radioisotopes
Water purification by electron beam bombardment
Potential electron beam production of biofuel feedstock from non-edible portion of plants
Plant photosynthesis dynamics research with radioisotopes
Health and Medicine
Nuclear medicine: Diagnostics
Nuclear Physics in Radiation Therapy
Safer homes: Smoke detectors and radon dosimetry
Accelerator Mass Spectrometry for the biosciences
Food irradiation: Food safety and worldwide reduction of crop loss
Medical device sterilization
Assessment of radiation health risks for deep space missions
Art and Forensics and Other Applications
Radiodating
Electrostatic accelerator industry for ion beam analysis and accelerator mass spectrometry
Neutron activation analysis
Ion beam analysis for rapid aerosol analysis and consumer product screening
Radioisotope tracer analysis
Ion implantation of semiconductors
Single-event efforts –microchip hardening
Electron beam material modification: industrial ceramics and polymer cross-linking
Stable isotope forensic science applications
Nuclear Science in the movies – art and education with nuclear astrophysics

As has been mentioned in the executive summary it is getting more difficult to attract funding for projects that begin to leave the mainstream focus of an individual grant or program and represent the first step towards a potential application. These initial research and development activities cannot be classified as fundamental research, nor do they fall in the category of technology transfer. The boundaries between the various federal funding agencies appear not to be well defined which could be the cause for these apparent funding gaps.

For example, nuclear medicine imaging used to be funded by the DOE Biological and Environmental Research (BER) division, but has been transferred to the National Institute of Biomedical Imaging and Bioengineering within the NIH. However, it is not clear that the goals of the two programs are the same and the perception in the community is that the funding is not as available for nuclear medicine imaging as it used to be. Similarly, the loss of funding from the Heavy Element Chemistry program from the DOE Basic Energy Sciences between FY2012 and 2013 has not been picked up elsewhere in the federal budget.

RECOMMENDATION

The interface between basic research and exciting innovations in applied nuclear science is a particularly vital component that has driven economic development, increased national competitiveness, and attracts students into the field.

We recommend that federal funding agencies provide and coordinate funding opportunities for innovative ideas for potential future applications. Where applicable they should explicitly support concurrent development of innovation from the basic research mission.

The 2009 DOE Office of Nuclear Physics initiative *Applications of Nuclear Science and Technology (ANS&T)* provided support to researchers at DOE laboratories and researchers at universities for research at the interface of basic research and innovations in applied nuclear science.

We recommend that the DOE Office of Nuclear Physics restart and expand this initiative. A reinvigorated ANS&T program should leverage the Nation's unprecedented technical assets developed by DOE in its laboratories and university scientists to bring additional benefits of nuclear physics research to all fields and industry.

3.1 DEFENSE AND SECURITY

It is clear that new security challenges and national defense will continue to create a need for innovative nuclear science applications, both in the established weapons programs that need to continue to manage a reliable stockpile stewardship program in the long-term absence of weapons testing, and in new areas of intelligence, nuclear security, interdiction and emergency response, nuclear forensics, counterterrorism, international safeguards and treaty verification. The applications in this area range from theoretical and experimental studies of fission product cross sections that are not well known, to the need for new radioisotopes to be created to help study reaction cross sections or to monitor international weapons programs. There is also a critical need to develop alternative detectors and imaging processes for homeland security needs to scan goods and cargo entering the United States. This particular need receives heavy investment from the commercial sector and has led to a national helium shortage currently that could be addressed by different detector and imaging technologies. Similarly, the need for new compact accelerator design and testing is evident for border security.

STOCKPILE STEWARDSHIP

Nuclear weapons have played a pivotal role in U.S. history, and are still a critical part of the national defense in that the U.S. maintains a credible "nuclear deterrent" in its nuclear weapons program. Since nuclear weapons testing was discontinued in 1992, "a science-based approach for annual certification of nuclear warheads with aging, replaced, or modified nuclear components was adopted by the DOE's Defense Program. The ability to certify performance of the U.S. nuclear stockpile in the absence of nuclear testing is embodied in what is now called the Stockpile Stewardship Program" [4,5]. This program includes extensive modeling and simulation of the nuclear components, as well as laboratory experiments and historical data analysis to better reduce the uncertainties in the models used to predict viability of the stockpile. There is currently a critical need for better data on the interaction of radiation and matter as the warheads age, in addition to a better understanding of materials in the extreme environment of high energy density.

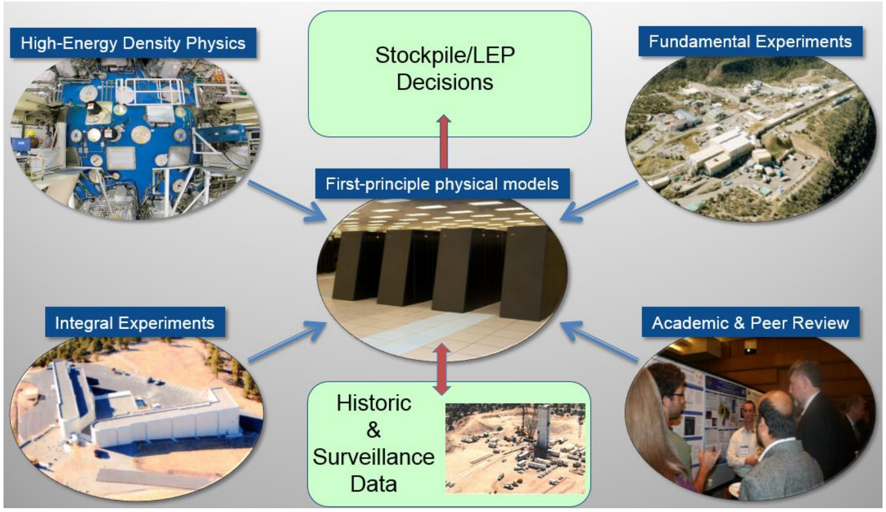

Figure 3.1.1 An overview of the Stockpile Stewardship program, showing the interconnections between modeling and experiment in nuclear science [5].

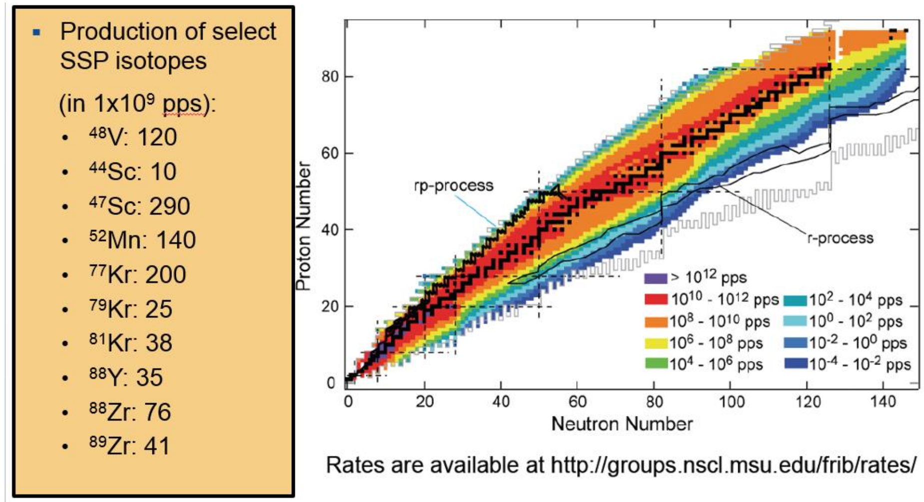

Figure 3.1.2 A partial list of long-lived radioisotopes of interest to the Stockpile Stewardship (SSP) program, together with the calculated production yields from FRIB (shown to the right). It may be possible to harvest previously unavailable isotopes from FRIB for critical information needed in the SSP [6].

Production and measurement of nuclear cross sections of new radioisotopes is also critical to this effort to obtain the best information on the extremely complex system that is a nuclear weapon [6]. This program represents a significant investment by the federal government into a direct application of nuclear science that has helped to prevent the military use of nuclear weapons worldwide for over 65 years.

ADVANCED SIMULATION TOOLS, AND COMPUTATIONAL APPLICATIONS OF "BIG DATA"

Partly as a result of the nuclear weapons program and its need for extensive libraries of information on every possible isotope involved in fission, nuclear science has developed extensive libraries of critical physical information. Also partly as a function of the massive experimental measurements performed in modern particle accelerator laboratories, extremely sophisticated data acquisition tools have also been developed in nuclear science. Finally, as the nucleus represents a system with forces unlike any other studied in the physical world, sophisticated theory has evolved in nuclear science as well. This combination of data libraries, extensive records of experimental results and computational modeling leads nuclear science to the forefront of what is now being referred to as "big data". An example of where nuclear science has pioneered this type of development is the National Nuclear Data Center (NNDC), housed at Brookhaven National Laboratory and supported by DOE to be a worldwide resource for nuclear data. The staff collects, evaluates and disseminates fundamental nuclear physics data for both research and applications of nuclear technology, and is a model for other sciences [7].

HOMELAND SECURITY: CARGO INSPECTION AND INTERROGATION

An important application of nuclear science is the development of radiation portal monitors at border crossings in the U.S. In light of the increasing possibility of non-state radiological terror threats, the U.S. has undertaken an ambitious border security program of constructing an extensive network of radiation portal monitors to prevent the illicit

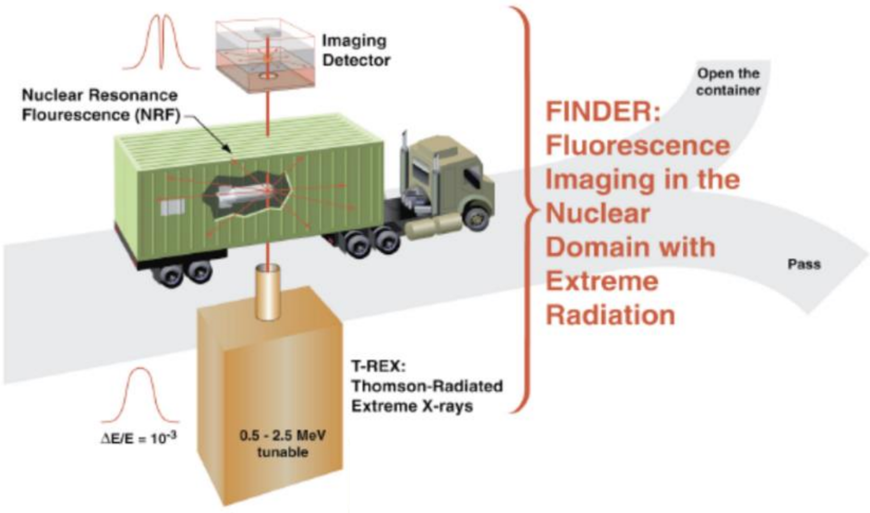

Figure 3.1.3 Conceptual diagram of how Nuclear Fluorescence Resonance (NFR) spectroscopy might be used with an x-ray source to interrogate cargo containers for special nuclear materials. NRF may provide a more sensitive and quicker confirmation of the presence of illicit nuclear materials [11].

transport of radiological materials into the U.S. The current system relies mainly on the detection of gamma-rays and neutrons, with a mixture of national laboratories and private industries responding to the national need by developing large scale portals that will screen entering cargo for the presence of radioactive materials that emit gamma rays or neutrons [8]. One of the unintended consequences of this rapid scale up of nuclear detection technology has been the extensive use of ^{3}He gas to build thermal neutron detectors, which has led to a national helium gas shortage [9] since 2009. Research and development continues in this area to adapt other applications of nuclear science to solving the problems of nuclear material interdiction at U.S. borders. For example, one recent effort has developed an alternative detector technology that can detect thermal neutrons (from special nuclear materials that emit them) with less expensive plastic scintillator technology and a cadmium foil that will absorb thermal neutrons and emit gamma rays instead, which the scintillators can detect and discriminate from non-neutron sources [10]. Still other research continues into active interrogation of cargo techniques that promise to be more sensitive to the presence of special nuclear materials. For example, since fissile elements such as uranium and plutonium exhibit distinct nuclear resonance fluorescence (NRF) signatures (known from fundamental research into nuclear structure), it is possible to use accelerator systems to produce penetrating gamma rays that can excite these NRF signatures within cargo containers. Proof of principle of this active cargo interrogation technique has been established [11], but research remains to be able to produce smaller, "fieldable" accelerator systems that would allow this technology to be used at border locations.

3.2 ENERGY AND CLIMATE

After almost 30 years of no new growth in the nuclear power industry, this town meeting was held at a time when the construction of 4 new nuclear power plants have been ordered nationally. The combination of a continued global demand for energy and the public realization that nuclear power does not contribute greenhouse gas emissions to the atmosphere has turned into an increased need for nuclear scientists in the energy sector. While nuclear power generation has continued to evolve over the past decades, there are pressing needs for research both in long-term fuel cycles, thermal load calculations, spent fuel transmutation and materials modification in high flux fields. Nuclear physics applications are also playing a central role in the identification of climate change processes with the development of Accelerator Mass Spectrometry techniques in paleoclimatology and tracing modern reservoirs and sources of carbon dioxide.

NUCLEAR REACTORS FOR POWER

An obvious societal application of nuclear science are the 100 commercial nuclear power plants currently in operation supplying almost 20% of the domestic electricity production in the U.S. There are more reactors in operation in the U.S. than in any other country, and the nuclear power industry provides more than 70% of the domestic energy production that does not contribute greenhouse gases to the atmosphere [12]. It is an enormous industry in the U.S., consisting of the power companies, nuclear power vendors, state and federal regulatory agencies and nuclear power research (both at EPRI and at various National Laboratories). Design improvements of the current "open" nuclear fuel cycle and development of advanced nuclear fission reactors include improved storage and monitoring of used nuclear fuel, environmental monitoring of all aspects of the power generation process, and better data about the fission and neutron absorption processes as a function of energy and nuclide involved. Simultaneous research and development is taking place for next-generation reactors, such as thorium-fuel reactors, considered potentially safer, more efficient, and which produce significantly less radioactive waste. Eventually, scientific advances seek to develop commercial fusion power, which produces even more energy from readily abundant hydrogen and helium sources, with almost no radioactive waste. With the imminent threat of both energy shortfalls in a growing world

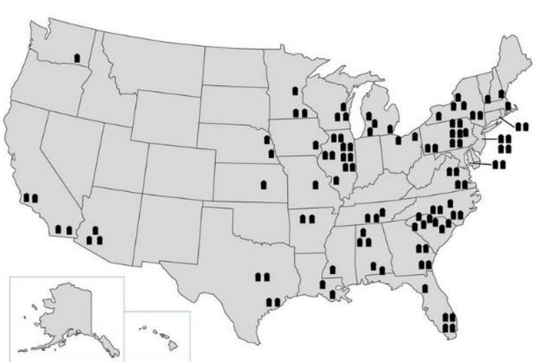

Figure 3.2.1 There were 104 operating commercial nuclear power reactors in the U.S. in 2010 distributed as shown on the left (since then 4 were shut down). These plants, for example the Limerick Nuclear Power Plants shown on the right, provide about 19% of the U.S. electricity production annually, and about 70% of the electricity produced without fossil fuel burning [13].

economy and global warming from the use of fossil fuels, nuclear power remains a very likely short-term option for power generation in the U.S., and if fusion power can be developed, perhaps the long-term solution as well.

ACCELERATOR ADVANCES FOR REACTOR SAFETY

With a nuclear power industry that saw a 30-year hiatus in building new power plants, many of the operating U.S. reactors are continuing well past their initial life-time estimates. Radiation damage of structural materials within a high-radiation field over extended periods of times (years or decades) have become a significant challenge to keep older power plants operational. Unfortunately, the structural defects due to intense radiation and thermal damage to common materials such as various types of steel are not well characterized without actually running experiments within operating nuclear power plants for years or decades to study the stress neutron damage causes in these materials. This is where low-energy electrostatic accelerators can provide an innovative solution. They can mimic long-term neutron damage in structural materials, by high-flux charged particle bombardment in a much shorter timescale (days to weeks of irradiation) [14]. These ion beam bombardment studies are currently ongoing to provide an accurate model of which types of materials need to be replaced at what level of radiation exposure within commercial power plants, simultaneously reducing operational costs and improving upon the already excellent safety record of the U.S. nuclear power industry.

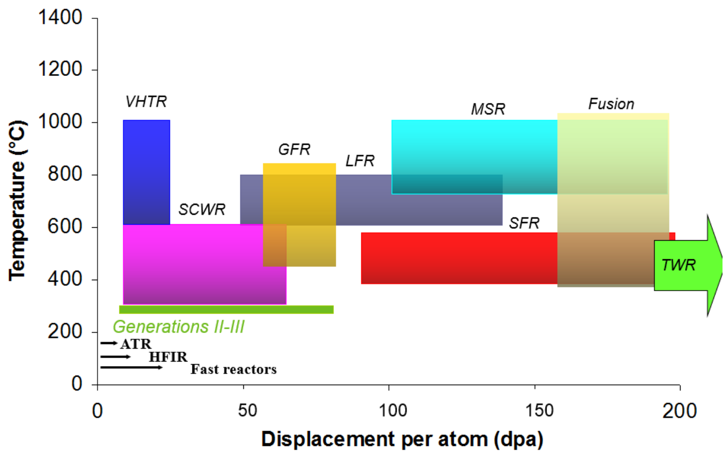

Figure 3.2.2 The extremes of temperature and particle flux expected for the next generation nuclear power reactors. Construction materials will have to be designed to handle these new extremes of temperature and radiation [14].

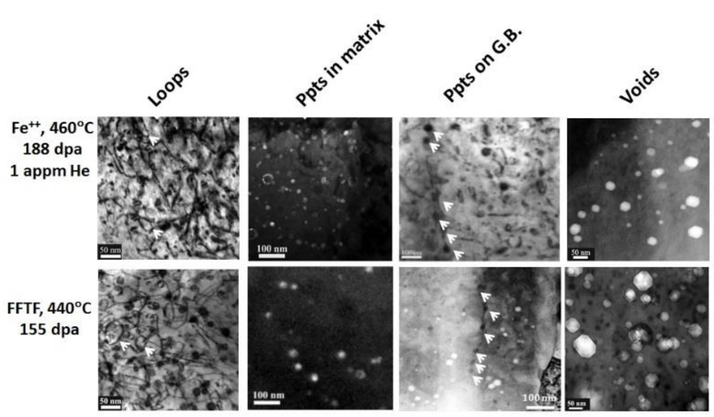

Figure 3.2.3 Mimicking metal defects from neutrons (bottom row) with Fe ions from an accelerator (top row). This ion bombardment can simulate years of neutron damage in days of irradiation, leading to safer, more cost efficient reactor designs [14].

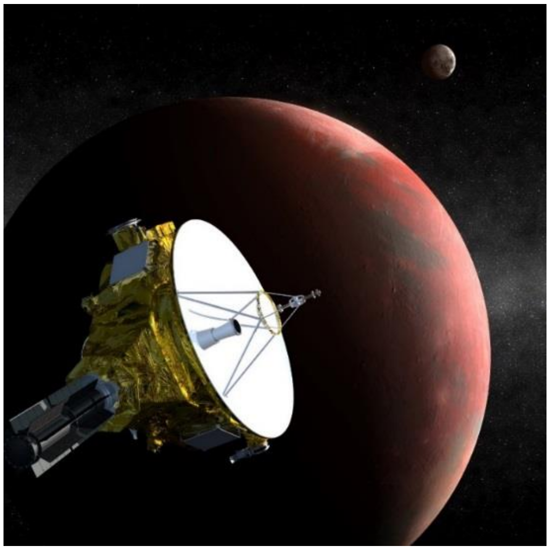

Figure 3.2.4 Artist's conception of the New Horizons spacecraft as it becomes the first spacecraft to ever visit Pluto in July of 2015. The radioisotope thermoelectric generator is visible as the large black object on the left, and will power the spacecraft for the 10-year journey and beyond [15].

NUCLEAR BATTERIES: RADIONUCLIDES FOR SPACE EXPLORATION

The U.S. space program has relied on nuclear science to power its deep space exploration probes over the past several decades. Given the significant cost of launching any material into space from the surface of Earth, historically in the tens of thousands of dollars per pound range with traditional NASA launch vehicles, deep-space missions away from the sun (where solar panels are impractical), require the use of exceptional batteries. Chemical batteries are far too short lived and heavy to provide the type of power required for the Mars explorers, solar system missions and other exciting space exploration programs. The solution has been the development and implementation of radioisotope thermoelectric generators (RTGs). RTGs typically consist of small quantities of long-lived separated radioisotopes that are used to provide a constant supply of heat, which is converted into a very stable electrical current for decades of power for spacecrafts. Research and development continues [16] into new RTGs that are made from non-fissile isotopes, which are safer in the event of launch malfunctions.

WELL LOGGING FOR OIL AND GAS EXPLORATION

One of the most successful commercial processes based on nuclear science is the development of nuclear well logging technology for the oil and gas exploration industry. Well logging is the process of characterizing the physical properties of the rock (or sediment) surrounding a test bore hole as a function of depth. Typically a radioactive source (e.g. ^{252}Cf) is lowered by wire through a test bore hole, together with an instrumentation pack that can measure the scattered neutrons from the radioactive source, as well as any induced gamma-ray emission and various other properties such as electrical conductivity. By correlating the response of the surrounding media to the probe's depth within the borehole, properties such as bulk density, porosity and the presence of hydrocarbons can be profiled in real-time as the instrumentation pack is lowered into a bore hole [17]. This is invaluable information for the oil and gas field exploration industry and is significantly faster than removing parts of the test bore for subsequent laboratory analysis.

CLIMATE-CHANGE MONITORING VIA ACCELERATOR MASS SPECTROMETRY

The development of extremely sensitive analytical measurement techniques in nuclear science, such as Accelerator Mass Spectrometry (AMS) has led to unprecedented sensitivity to certain isotopes in environmental samples. While this has had a revolutionary impact on several different sciences, one particular environmental application has been the global ocean reservoir estimates of carbon dioxide. This is a critical parameter in any global warming model, as the Earth's oceans absorb atmospheric gases, and if the carbon dioxide concentration of the atmosphere is increased by the use of fossil fuels, what fraction of this increase will be sequestered into the planet's oceans as dissolved gases. The chemical dissolution of gases into salt water is well understood at the surface of the water as a function of gas pressure and temperature. What was not well understood before AMS studies became available, was the circulation time between the ocean's surface and the deep ocean depths (where most of the potential water reservoir is located). If the deep ocean mixes rapidly with the surface ocean, then there may be an enormous reservoir in which to store excess atmospheric carbon dioxide. AMS measurements of a radioactive form of carbon (^{14}C) are capable of easily measuring the deposition of radioactive carbon from atmospheric weapons testing into the ocean. Even though the radioactivity is present at any given location in minute quantities, AMS is so sensitive that reliable measurements of ^{14}C can be made on small volumes of seawater from all over the ocean's surface, as well as at various depths with traditional sampling techniques made by NOAA vessels. The preliminary AMS results from the Southern and

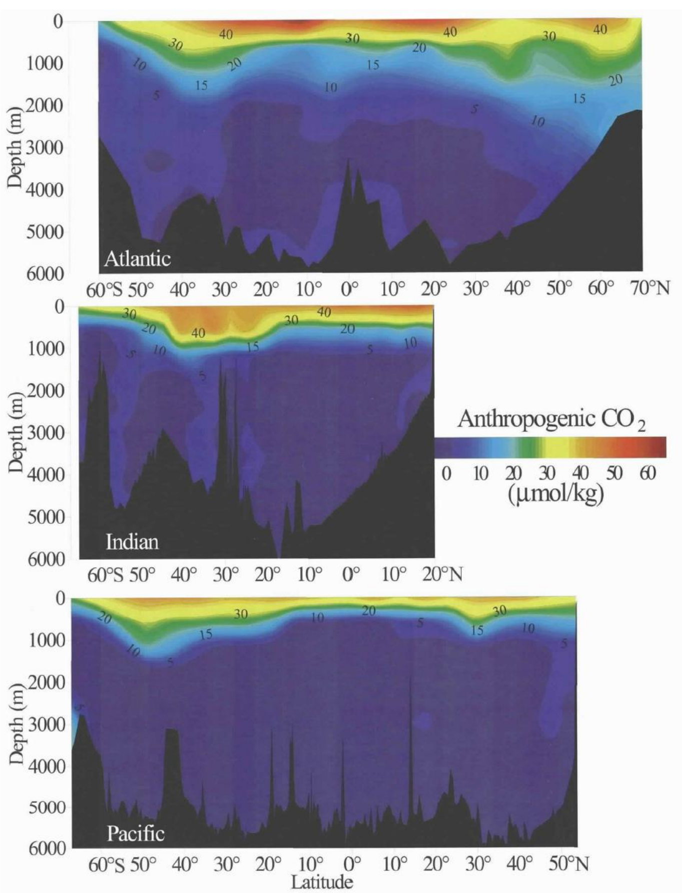

Figure 3.2.5 Zonal mean distributions of estimated anthropogenic CO_2 concentrations (in units of µmol/kg) along north-south transects in the Atlantic, Indian and Pacific oceans. These data represent years of collection and analysis of ^{14}C data from Accelerator Mass Spectrometry (AMS), and this high-precision information was not available to climate scientists before the development of AMS [18].

Pacific Oceans showed that circulation times between the shallow and deep ocean were on the timescale of millennia [19,20], which means the atmospheric composition could change drastically with no noticeable reservoir effect in the majority of the ocean for over a thousand years. This critically important measurement is still being reproduced in every ocean at many different locations and depths, to best define the global climate change models.

WATER PURIFICATION BY ELECTRON BEAM BOMBARDMENT

Less than 1% of the liquid water available on this planet is suitable for consumption, and increasing population growth and global industrialization has stressed what natural freshwater sources are available. There is a clear need for cost-effective water purification systems, both for industrial wastewater and municipal water, and nuclear science has developed an application that may well be part of the solution to critical water shortages. Using electrostatic accelerator technology to produce high-flux electron beams at MeV energies has been shown to effectively decontaminate wastewater, both with respect to microbial contamination, but also with respect to most common organic pollutants [21]. The electron beam technology causes extensive radiolysis of the water, and the radical oxygen species produced in the water do the active decontamination of the water. In this respect, electron beam accelerators are a mature nuclear technology that can work on industrial or municipal waste water solutions, without losing performance in highly turbid waters where UV light sterilization can fail. While a very promising technology in terms of wastewater purification, the large capital costs of standard electrostatic accelerators has prevented more than about 20 pilot purification plants being constructed worldwide. However, as part of ongoing research and development into smaller, lower cost accelerator systems, and the increasing price of clean water, there remains a niche where this nuclear science technique may play a critical role in the future.

3.3 HEALTH AND MEDICINE

There has been a rapid growth in nuclear science applications in health and medicine, specifically with the impending FDA approval of new radioisotopes for use in human medicine. Pharmaceutical companies lead the demand for more radioisotopes and innovative radioisotope production methods to address more sophisticated imaging and therapy techniques. A recent trend is to identify radioisotopes or combinations of radioisotopes that will act as "theranostics": compounds that contain radioisotopes that can be used to image (diagnostics) as well as treat (therapy) tumors. Commercial medical cyclotron use is expanding worldwide very rapidly, but there were a variety of presentations that demonstrated innovative new nuclear physics approaches to yield novel radioisotopes and ion beam treatments that are not currently available with the typical medical cyclotron facility.

NUCLEAR MEDICINE: DIAGNOSTICS

Arguably the application of nuclear science that affects the most people every year lies in the field of medicine. Nuclear medicine diagnostics, or "imaging" uses radiopharmaceuticals (a radionuclide either by itself or attached to a molecule) together with specialized imaging instrumentation to detect the radioactivity in the body after oral, inhalation, or intravenous administration. Radiopharmaceuticals are used to assess normal physiologic processes, diagnose and treat diseases, measure the distribution of drugs, and monitor treatment effectiveness. Radiopharmaceuticals have been developed to study a wide range of normal processes and disease states, including normal brain function, aging, neurodegenerative diseases, cardiovascular disease, and cancer. A list of

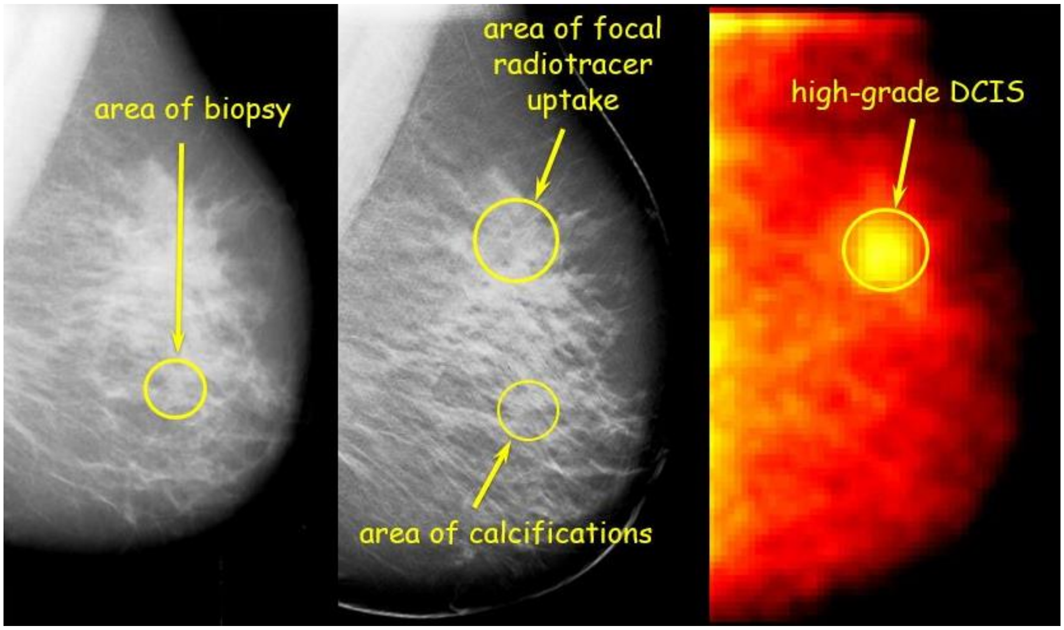

Figure 3.3.1 Combined X-ray and nuclear medicine breast scans: planar X-ray (left), X-ray tomosynthesis slice (middle), and nuclear medicine tomosynthesis slice (right). The combination of radioisotope labeling and tomography can yield accurate information about a tumor that was missed from regular X-ray tomography [22].

Table 3.3.1 Commercially Available Tomography Radiopharmaceuticals (adapted from [4]).

Trade Name	Radiopharmaceutical	Clinical Indication
Positron Emission Tomography (PET) Radiopharmaceuticals		
Ammonia N13	^{13}N-Ammonia	Myocardial blood flow
Cardio-Gen	^{82}Rb-Rubidium chloride	Myocardial blood flow
Florbetapir F18 [**]	^{18}F-styryl-pyridine	Amyloid Plaques - Alzheimer's
Fluorbetabane F18[#]	^{18}F-styryl-pyridine	Amyloid Plaques - Alzheimer's
Flutemetamol F18[#]	^{18}F-hydroxy-benzothiazole	Amyloid Plaques - Alzheimer's
Fluorpiridaz F18[#]	^{18}F-pyridazinone	Myocardial blood flow
Fludeoxyglucose F18	^{18}F-Fluorodeoxyglucose	Oncology, myocardial viability
Sodium Fluoride F18	Sodium ^{18}F-fluoride	Bone scans
Single Photon Emission Computed Tomography (SPECT) Radiopharmaceuticals		
Chromitope Mallinkrodt	Sodium ^{51}Cr-chromate	Red blood cell labeling
Ga-67	^{67}Ga-Gallium citrate	Soft tissue tumor, Inflammation
In 111 oxyquinoline	^{111}In oxyquinoline	Luekocyte and platelet labeling
MPI Indium DTPA In 111	^{111}In Pentetate disodium	Cerebrospinal fluid kinetics
ProstaScint	^{111}In Capromab Pendetide	Prostate tumor
Octreoscan	^{111}In-Indium Pentetreotide	Neuroendocrine, gastroenter. tumors
Zevalin	^{111}In -Ibitumonmab iuxetan	Non-Hodgkin's lymphoma
Sodium Iodide I 123	Sodium ^{123}I-iodide	Thyroid uptake
Datscan	^{123}I-Ioflupane	Striatal dopaminae transporters
Adreview	^{123}I-Iobenguane	Pheochromacytoma, neuroblastoma
Glofil	^{125}I-Iothalamate	Glomerular filtration measurement
Jeanatope	^{125}I-human Serum Albumin	Total blood and plasma volume
Megatope	^{131}I-human Serum Albumin	Total blood and plasma volume
Bexxar	^{131}I-Tositumomab	Non-Hodgkin's lymphoma
Sodium Iodide I 123	Sodium ^{123}I-iodide	Thyroid uptake
Technetium Generator	^{99m}Tc-Pertechnetate	Thyroid, salivary and parathyroid
Technelite		Glands, ectopic gastric mucosa
Ultra-Technekow FM		Dacryocystography, cystography
Neurolite	^{99m}Tc-Bicisate (ECD)	Cerebral perfusion
Hepatolite-CIS	^{99m}Tc-Disofenin (DISIDA)	Hepatobiliary function
Ceretec	^{99m}Tc-Exametazine	Cerebral perfusion
Pulmolite	^{99m}Tc-Aggregated albumin	Pulmonary perfusion
Choletec	^{99m}Tc-Mebrofenin	Hepatobiliary function
Osteolite	^{99m}Tc-Medronate (MDP)	Bone imaging
Technescan MAG3	^{99m}Tc-Mertiatide	Renal function
Techneplex DTPA	^{99m}Tc-Pentetate	Renal funct., radioaerosol ventilation
Phosphotec Pyrolite Pyro	^{99m}Tc-Pyrophosphate	Infarct imag., red blood cell labeling
Cardiolite Miraluma	^{99m}Tc-Sestamibi	Myocardial blood flow, breast tumor
DMSA	^{99m}Tc-Succimer (DMSA)	Renal function
Sulfur Colloid	^{99m}Tc-Sulfur Colloid	Liver/spleen gastric empt., GI bleeds
Myoview	^{99m}Tc-Tetrofosmin	Myocardial blood flow
Thallium	^{201}Tl-Thallium chloride	Myocardial blood flow, parathyroid
Xenon	^{133}Xe-xenon gas	Pulmonary ventilation

Figure 3.3.2 "Gamma Puck": Handheld detector with a tungsten shell and tungsten collimators. A radiopharmaceutical is used to identify sentinel lymph nodes with cancer involvement during breast cancer surgery. This Jefferson Lab and University of Virginia Medical Center developed gamma camera can be used to save repeated surgeries for patients [23].

42 commercially available radiopharmaceuticals and their target disease diagnostic is given in Table 3.3.1 (adapted from [4]). Literally tens of millions of Americans are experiencing some form of nuclear medicine diagnostics every year [24]. Together with the improved health benefits of this innovation, comes the clinical and industrial base that must supply the radioisotopes in a pure form in a timely manner, as well as those companies that supply the advanced medical computerized tomography scanners. Research and development is continuing in this field and medical cyclotrons are another growth industry. There were over 670 medical cyclotrons in operation in 2011, and that number is growing between 5-10% per year [25].

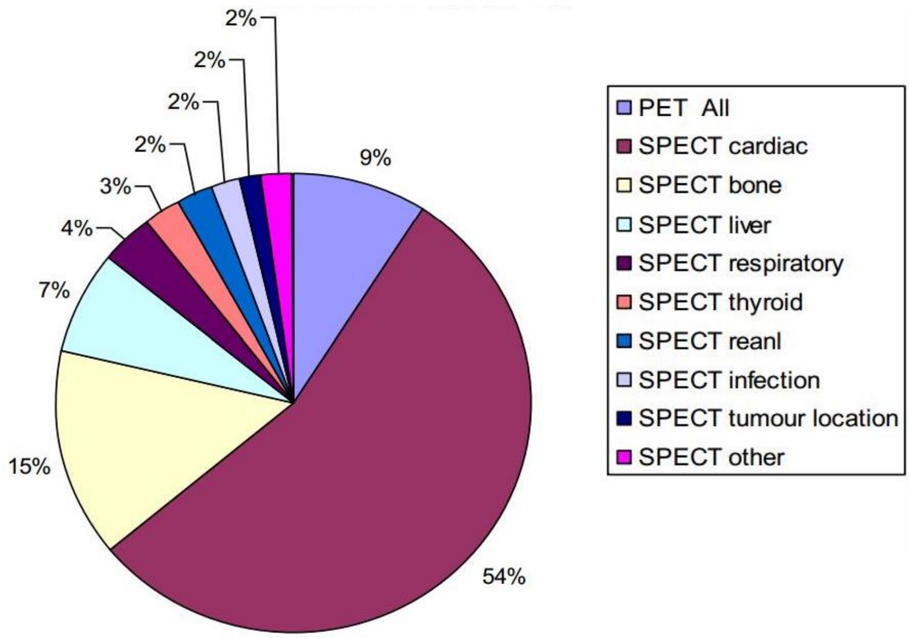

Figure 3.3.3 Nuclear medicine diagnostic procedures by type. Positron Emission Tomography (PET) scans and Single Photon Emission Computerized Tomography (SPECT) accounted for over 17 million procedures in 2008 [4].

NUCLEAR PHYSICS IN RADIATION THERAPY

Another area where nuclear physics plays a pivotal role in medicine involves the use of radiation to treat disease. Radiation therapy has long been used as a tool to kill cancer cells by damaging their DNA with targeted high-energy radiation. X-rays, gamma rays, and charged particles are all types of radiation used for cancer treatment. These may be delivered by an accelerator or source outside the body, or from radioactive material placed in the body near tumor cells or injected into the bloodstream. Together with chemotherapy and surgery, radiation therapy represents one of the mainstays in cancer treatment today. Of the roughly one million new cases of cancer in the U.S. every year, about half will involve radiation therapy of some form [26]. In addition to playing a role in advancing delivery mechanisms for radiation treatment, nuclear physics is critical to treatment planning, which begins with imaging (CT, MRI, or PET) for simulation. After imaging, the radiation oncologist determines the area to be treated, the radiation dose to be delivered, and any allowed normal tissue dose. The optimal paths for radiation delivery are then determined through simulation planning software programs that model the interactions of the radiation through the patient, taking into account all relevant physics. In image-guided radiation therapy, repeated imaging scans are performed during treatment to identify changes in a tumor size and location, and to allow re-simulation as needed to decrease the dose to normal tissue.

The use of proton beams for radiotherapy is rather new, and there is exciting potential for continued growth of this type of radiation therapy. Due to the fundamental nuclear physics of the Bragg curve that describes the energy loss of ionizing proton radiation as the particles traverse matter, proton beams deposit dose in tissue predominantly in a

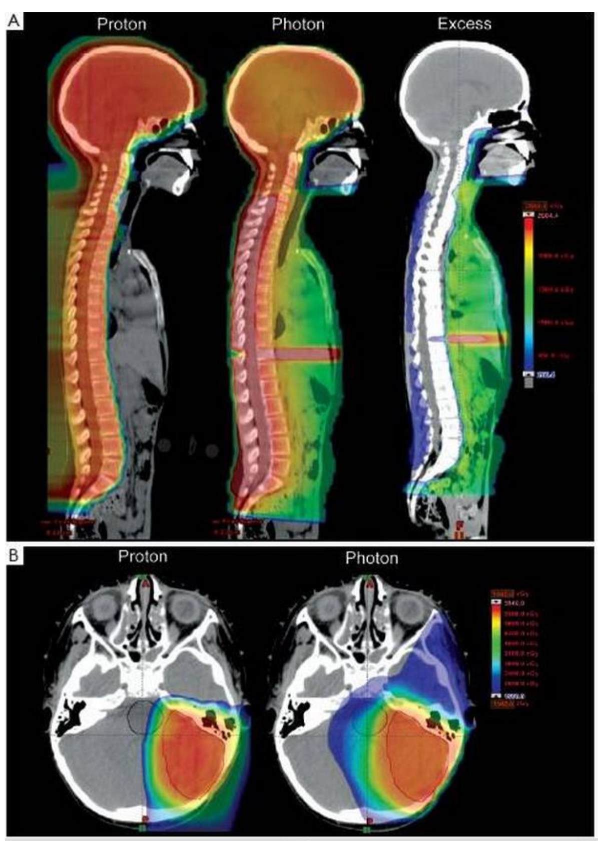

Figure 3.3.4 A comparison of proton and photon treatment dosages received for a child treated with craniospinal radiation. A. Sagittal images of proton and photon plans are depicted on the left, and a subtraction of the two images yields the excess dose deposited from photon treatment highlighted on the right; B. Transverse images of proton and photon based boost plans. Dose to the brainstem and temporal lobes is shown to be reduced with protons [27].

small, controllable, region at the end of their path - and do so with less cell damage along the way. This means that proton beam therapy should be able to deliver higher doses of radiation to a tumor, while reducing the radiation exposure of normal tissue [28,29].

Another tool of radiation therapy is the use of radioisotopes to deliver radiation internally to a tumor site. The availability of new radioisotopes is expected to expand the efficacy of this option in the future. A particularly exciting avenue for this is the interdisciplinary development of tumor-targeting compounds that may be combined with diagnostic and/or therapeutic radiation at the molecular level.

Already major applications of nuclear science, continued research and development into accelerator technology, dose monitoring detection, simulation, imaging and radioisotope production will continue to improve cancer treatment and provide innovation for medicine in the next decade.

The positive economic impact of nuclear physics innovation in healthcare is dramatic. As just one example, the construction of a single new proton therapy facility has been estimated to generate a total of $287 million in sales to its local economy, create 244 permanent and 198 construction-related jobs, provide $90.5 million in labor income, and nearly $12 million in tax revenues over a span through the first five years of facility operation [30]. This is just a single proton therapy facility. Currently, most developed countries have at least one radiotherapy unit (albeit typically photon) available for every 250,000 people [31].

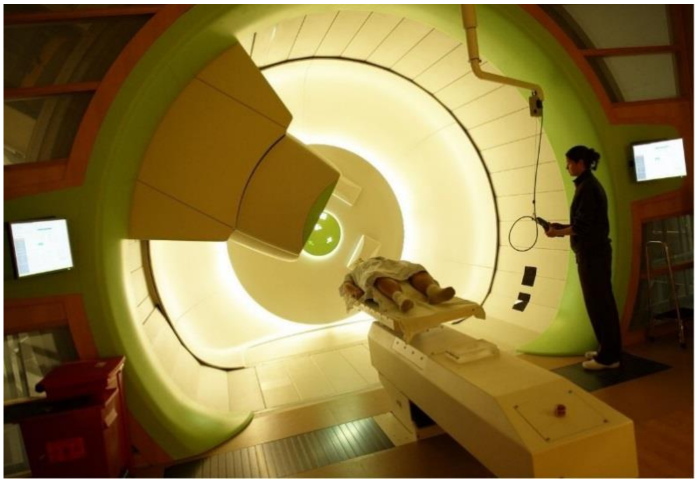

Figure 3.3.5 A modern proton therapy treatment center at the Children's Hospital of Philadelphia [32].

Safer Homes: Smoke Detectors and Radon Dosimetry

Another practical application of long-lived radioisotopes plus the nuclear science to detect the decaying particles is the modern smoke detector – required outside every bedroom in every new home construction in the U.S. The use of smoke detectors (plus the reduction in the number of smokers) has led to a dramatic decline in home fire deaths in the U.S. over the past two decades of their widespread use. Over 90% of homes in the U.S. currently have smoke detectors, and the risk of dying in a home structure fire is cut in half in homes with working smoke alarms. Still there are over 3000 civilian deaths per year in home fires, the majority in homes without a working smoke detector [33]. What is less well known about smoke detectors is that they operate on the electronic detection of alpha

Figure 3.3.6 A residential smoke detector [35].

particles that decay from a long-lived ^{241}Am radioisotope. When smoke particles interrupt the continuous decay of alpha particles traversing a small air gap, the alarm sounds. While the batteries need to be replaced to operate the electronics in older versions, the alpha source has such a long half-life it never needs to be replaced for standard residential use. This improved home safety has markedly changed U.S. quality of life due to the application of nuclear science. Related to improved home safety is the discovery and characterization of sources of radon gas in our homes. While seepage of this heavy radioactive gas from soils and rocks into home basements has occurred since house construction began in the U.S., the health risks became worse when our society became more energy conscious and started sealing residential buildings more efficiently – often trapping higher levels of radon within the home. Our realization of the health risks associated with atmospheric radon concentrations have occurred only over the past two decades as nuclear science dosimetry and health physics have improved to make such measurements. As a result, there are building code modifications and EPA websites [34] alerting home owners to both the risk of radon inducted lung cancer (it is estimated that there are still 20,000 radon-related lung cancer deaths per year in the U.S. [36]) as well as measures to reduce the risks.

ACCELERATOR MASS SPECTROMETRY FOR THE BIOSCIENCES

A revolution has occurred in drug development due to the innovative development of a nuclear science method into an ultra-sensitive analytical tool useful in pharmacokinetics (PK) [37,38]. PK refers to the movement of a drug into, through, and out of the body, encompassing its absorption, bioavailability, distribution, metabolism, and excretion. Because of the expansion of Accelerator Mass Spectrometry (AMS) from radiodating applications to bioscience applications, it has become possible to use AMS to measure radiolabeled drugs and their metabolites at very low levels in the body. AMS is a thousand times more sensitive than regular mass spectrometry because of the nature of ion source and the acceleration potential of typical nuclear science accelerators. Because it measures isotope ratios very precisely, AMS has now made it possible to characterize the PK of compounds following administration to humans of a minute, sub-pharmacologic dose, a microdose [39]. This has been shown to be much more realistic in its analysis of PK in biological systems, compared to the crude chemical studies where rats are given tens or hundreds of times the therapeutic dose in order to measure biological effect (or side-effects). AMS is now considered the most promising way to improve the efficiency and the accuracy of drug development [40]. Pharmaceutical companies are now purchasing AMS systems of their own, together with nuclear scientists to run them, and to use this tool in their biomedical research efforts in an effort to identify drug effects (both positive and adverse) early in the drug development process. Drug discovery and development is a multibillion dollar industry in the U.S. and over the past decade this nuclear science tool has transformed the industry standard.

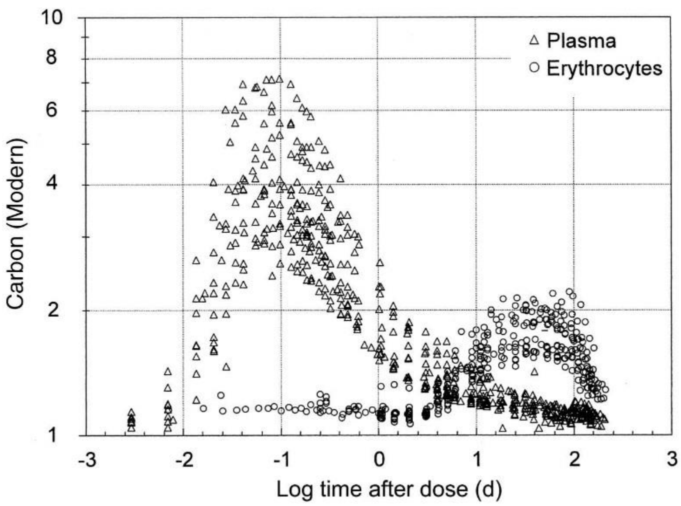

Figure 3.3.7 Radioisotopic ^{14}C content of plasma and red blood cells (RBC) of 13 human volunteers shown from 5 min to 200 days after a single 100 nCi dose of ^{14}C-folic acid was ingested. The data show maximum folic acid delivered to the plasma at ≈ 24 h and the data revealed a 6.1 day maturation for RBC. RBC lifespan is clearly 120 days, and none of this information was known before the high-sensitivity of Accelerator Mass Spectrometry was developed [41].

FOOD IRRADIATION: FOOD SAFETY AND WORLDWIDE REDUCTION OF CROP LOSS

An important global application of nuclear science occurs with food irradiation. This is the practice of passing a high flux of gamma rays, x-rays or accelerated electrons through food to kill microbacteria present in it. Gamma rays are obtained from radioactive sources (usually ^{60}Co) produced by reactors, while electrostatic accelerators provide electron beams and if a metal plate is used at the end of an electron beam, x-rays. Gamma rays and x-rays are most commonly used because of their greater penetration power. All three forms of ionizing radiation destroy (or "pasteurize") microbacteria on the surface and within the food, reducing the likelihood of foodborne pathogens and increasing food safety. It also has the benefit that the shelf life can be greatly extended for some fruits and vegetables. The U.S. has one of the safest food supplies in the world and access to reliable refrigerated shipping throughout the mainland U.S. Even so, there were estimated to be more than 48 million foodborne illnesses in the U.S. per year and more than 3000 deaths per year [42]. To reduce these numbers, nuclear science has helped the U.S develop one of the largest food irradiation industries in the world. In 2010, more than 100,000 tons of food were irradiated before market [43]. While Europe remains wary of the technology, Asia has recently surpassed the U.S. in applying this technology, with an estimated 285,000 tons of food irradiated in 2010 [43]. Globally, it is estimated that more than 1/3 of all food grown on Earth spoils before it can reach the market [44], and food irradiation in Asia where a single network of refrigerated rail cars doesn't exist, both food safety and food supplies can be dramatically influenced by this nuclear science application.

Figure 3.3.8 Strawberries that have been irradiated compared to those that haven't after several days without refrigeration. In addition to improving food safety, shelf life times are significantly increased which allows for more food to be delivered globally before spoilage [45].

3.4 ART, FORENSICS AND OTHER APPLICATIONS

Even in fields as diverse as art authentication, anthropology, forensic science and materials science, a significant growth in innovative uses of nuclear science has been observed in the last decade. Examples include the application of small accelerators in a variety of fields, such as ion beams for pollutant scrubbing and elemental analysis of chemical contaminants in consumer products, as well as in areas such as manufacturing and quality control.

RADIODATING

One of the most well-known innovations of nuclear science is the method known as radiodating, a technique that won the 1960 Nobel prize in Chemistry for Williard Libby. He used the long-lived radioisotope of ^{14}C that is created by cosmic ray interactions in the Earth's atmosphere and is subsequently absorbed at a low level into all living organic material. With a half-life of 5730 years, this radioisotope decays away on a timescale that closely matches the development of human civilization, so it has been an invaluable tool in anthropology to study the history of human development. Repeated media attention to stories such as the Ice Man, or Kennewick Man [46] reinforce the importance of this nuclear science tool in other disciplines such as history, sociology and anthropology. Less well-known, but equally important are the other radioisotopes used for dating, such as ^{210}Pb used to date lake sediments over the timescales of decades [47], and the various geochronometers [48] such as the potassium/argon, rubidium/strontium and uranium/lead pairs of radioisotopes that have allowed us to accurately date the age of rocks found in the earth. These same geochronometers have been used on meteorites, which has allowed us to accurately estimate the age of the solar system. This basic nuclear science technique of using radioactive decay to measure the age of objects has had transformational impacts on archeology, history, geology, astronomy and the environmental sciences.

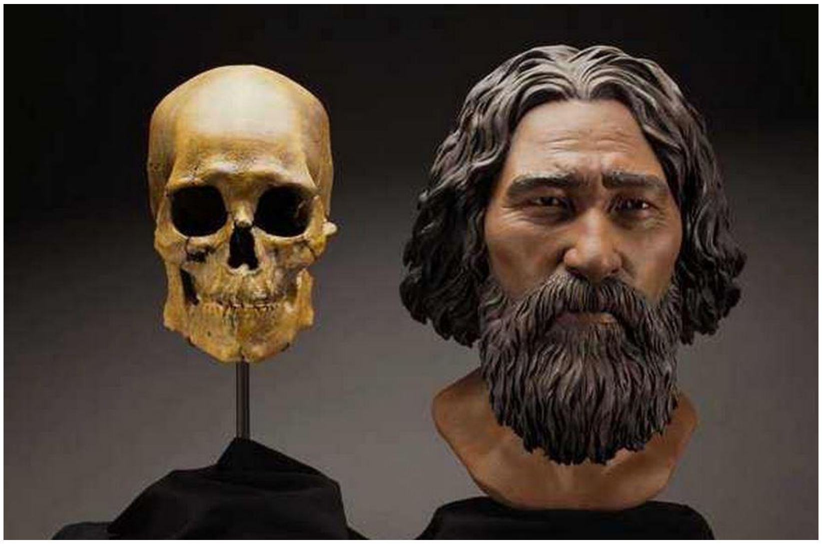

Figure 3.4.1 A facial reconstruction of Kennewick Man, a skeleton discovered in the Columbia River Valley of Washington state, which was radiodated to be over 9,000 years old, making him one of the early settlers of North America [49].

ELECTROSTATIC ACCELERATOR INDUSTRY FOR ION BEAM ANALYSIS, ACCELERATOR MASS SPECTROMETRY

One of the innovations that is well recognized as a product of nuclear science fundamental research and development is the electrostatic particle accelerator. Earliest examples began operating in the 1930's, and they have played a critical role in understanding the structure of the atom and the nucleus. Since so many applications of accelerated ions have been developed over the past few decades the industry of making these instruments has grown markedly in the past seven years. While there remain only two commercial manufacturers of standard electrostatic accelerators (National Electrostatics Corporation – Middleton, WI and High Voltage Engineering - Amersfoort, Netherlands), the number of systems being constructed recently has increased dramatically. As little as ten years ago, 3 or 4 systems would be manufactured at NEC per year, while currently NEC is processing over 30 orders for systems or upgrades, and there is effectively a two-year backlog to meet demand. About half of these new orders are coming from the explosion of Accelerator Mass Spectrometry systems used in the pharmaceutical industry, but ion beam analysis and ion beam implantation/modification systems represent almost a third of the orders [50]. Given the U.S. economic stagnation between 2009 and 2012, the fact that this multi-million dollar industry has experienced an unprecedented expansion during this time indicates the vitality of this nuclear science "spin off".

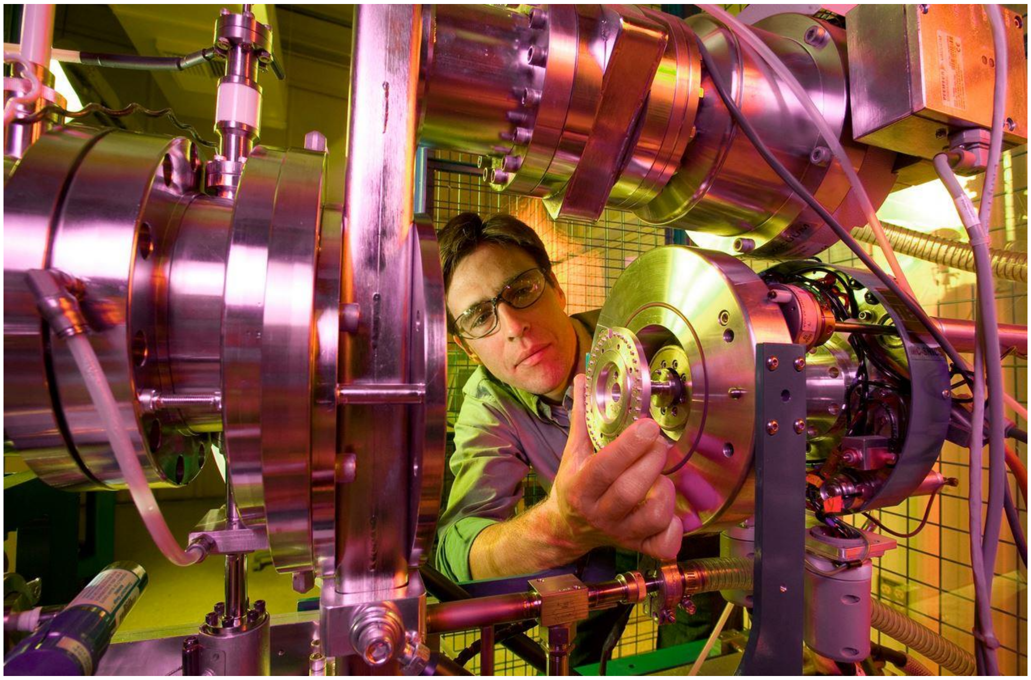

Figure 3.4.2 Staff Scientist Ted Ognibene loading samples in the 1MV Bio-AMS system at the Center for Accelerator Mass Spectrometry at Lawrence Livermore National Lab. Accelerator Mass Spectrometry is one of the new areas that is driving significant growth in the commercial accelerator manufacturing sector [51].

NEUTRON ACTIVATION ANALYSIS

The idea of using neutrons as an analytical probe for elemental analysis was first proposed and demonstrated by Von Hevesy and Levi for the analysis of trace quantities of rare earths in geological materials in 1936 [52]. Since then, the excellent sensitivity, selectivity and precision of neutron activation analysis (NAA) have made it one of the most versatile and widely employed elemental analysis techniques [53]. Because most materials are "transparent" to the probe, neutrons, and the signal, emitted gamma rays, there are few matrix effects associated with the analysis and standardization of the measurement as simple and straightforward. Moreover, because little, if any, sample manipulation is required, NAA is a highly sensitive technique that is relatively free of reagent and laboratory contamination. As a result, NAA is one of the primary reference techniques employed by the National Institute of Standards and Technology for the certification of standard reference materials.

Since NAA was selected for the multi-element trace analysis of the small, irreplaceable, geological samples returned from the Apollo mission numerous alternative trace-element analysis techniques have become available. In particular, atomic absorption spectrometry, inductively-coupled plasma atomic emission spectrometry, and inductively-coupled plasma mass spectrometry now rival or exceed the sensitivities that can be achieved with NAA in many cases and these techniques have gradually replaced NAA in a great number of applications. Neutron activation analysis still, however, continues to play a critical, unique role in those applications wherein it is not possible and/or cost effective to dissolve or digest the samples prior to analysis; in those applications where the sample mass is limited; and in those applications where it is necessary to retain and archive the original sample. For example, NAA is routinely used to analyze obsidian - a volcanic glass that is difficult to dissolve - in archaeometry studies to establish trade routes and interactions among ancient peoples. Similarly, NAA is the method of choice for the analysis of tiny samples of human hair and nail clippings in large epidemiology studies used to examine the role of trace element nutrition on human health.

ION BEAM ANALYSIS FOR RAPID AEROSOL ANALYSIS AND CONSUMER PRODUCT SCREENING

Several applications of electrostatic particle accelerators have been developed in cases where ion beam analysis can deliver information about a sample more rapidly, non-destructively and quantitatively than standard chemical analyses. In these cases, nuclear science can provide valuable analytical measurements that have yet to be matched by other chemical techniques. An early example where ion beam analysis provided a more rapid, quantitative and non-destructive measurement of an environmental sample was the development of Particle-Induced X-ray Emission (PIXE) techniques to measure elemental concentrations in aerosols [54]. Previously, atmospheric aerosols collected on a filter had to be manually separated, digested in acid and analyzed destructively by chemical means. PIXE analysis required no further processing of the filter, was rapid, non-destructive and quantitative for most elements between Na and Pb. It revolutionized the analysis of atmospheric aerosols that continues today with networks of air samplers that lead to unprecedented source apportionment of air pollution. Another practical example is the use of non-destructive PIXE analyses to authenticate artwork at leading museums [55]. More recently, this technique and other ion beam analysis techniques have been used to

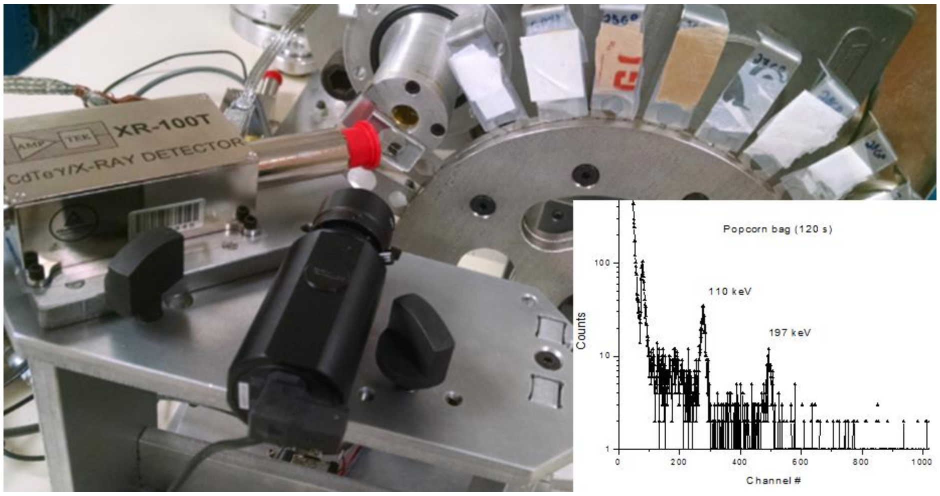

Figure 3.4.3 Particle-Induced Gamma-Ray Emission screening of paper samples in air. Perfluorinated coatings on the paper exhibit characteristic ^{19}F γ rays (shown in inset) [59].

screen consumer products for the presence or absence of halogenated chemicals [56]. These chemicals are persistent, bioaccumulative and toxic, and many have been found to pose a risk to human health [57,58]. Again, the advantage to ion beam analysis is that analytical detection of characteristic x-rays or gamma-rays from the surface of a material can identify unambiguously the presence or absence of halogens applied as flame-retardants or to provide water and stain-resistance to that surface. The test can be more than 10 times faster and less expensive than traditional wet chemical methods, and because it is non-destructive it can serve as a rapid screening test that cannot be accomplished with any other technology currently.

ION IMPLANTATION OF SEMICONDUCTORS

One of the earliest applications of accelerator technology developed in nuclear science was the U.S. semiconductor industry, when it began to flourish in the 1970's. In order to make an appropriately sized band gap in a semiconductor material (such as silicon), doping the wafer with an electron-poor or electron-rich element of a similar ionic size will

Figure 3.4.4 A 200 keV Danfysik Ion Implanter installed at the Ion Beam Materials Laboratory at LANL [60].

lead to the creation of p-type and n-type semiconductors. The microelectronics revolution was based upon the development of these materials and ion implantation from accelerators was the initial way to achieve the most uniform doping of one element into a controlled depth within a crystal of another element. As the field has evolved, lower energy ion implantation methods have become more prevalent (such as plasma immersion ion implantation), where a mixture of thermal and ion implantation methods can produce more uniform doping with less structural damage. Still the impact of nuclear science technology on the birth of the semiconductor industry was significant and still today high-energy ion bombardment is still used for various purposes. For example, during the Cold War fears about radiation resistance of sophisticated microchips that control almost everything that moves led to a program of testing "radiation hardness" of microchip devices at heavy ion accelerators around the U.S. in the 1980s-1990s. Still today, the "single-event effect" of ionizing radiation can wreak havoc on digital electronics, and the methods developed to protect and radiation harden electronics at large accelerator facilities has had spin-off effects on all sorts of other microchip manufacturing processes which prepare electronics for avionics, both military and civilian, space exploration and nuclear power generation [61].

ELECTRON BEAM MATERIAL MODIFICATION: INDUSTRIAL CERAMICS AND POLYMER CROSS-LINKING

Electrostatic accelerator technology developed from nuclear science plays a key role in several materials science fields, and has the promise to replace several thermal industrial processes with ion bombardment processes in several new areas of materials science as well. The most widespread of these techniques involve high-intensity pulsed electron beam bombardment of ceramic or polymeric surfaces [62]. Depending on the acceleration voltage, ceramic surfaces can be sintered or polymer surfaces melted with a single pulse to a depth of up to 100 μm. This localized surface modification can be applied to a wide area (compared to lasers) but at a very shallow depth without heating the rest of the material (compared to thermal processes). While still an evolving field, commercial success has

Figure 3.4.5 An automotive piston with its surface modified by electron beam bombardment to aid in oil retention [63].

already been found in the surface alloying of metals which adds corrosion resistance to materials. Similarly, the intense heat can cause polymeric cross-linking of surfaces that add strength to a polymer without the use of excess volatile organic compounds in chemical reactions on the surface.

STABLE ISOTOPE FORENSIC SCIENCE APPLICATIONS

While most applications developed from nuclear science rely on radioactive decay, or some nuclear property accessible only with high energy accelerators or reactors, there are many geochemical and forensic science discoveries which rely simply on the pioneering nuclear science studies of isotopic mass distributions observed in the environment. While the most prominent of these might be the stable isotope ratio thermometers used to measure paleoclimatology in ice cores [64], there has been a revolutionary impact of stable isotope measurements in the forensic sciences. Examples include the published correlation between stable isotope ratios of oxygen and hydrogen in hair on geographic location within the U.S. [65]. Basically, this means that "we are what we eat", and the stable isotope ratios for these elements distributed in our bodies reflect the stable isotope ratios of the water in our immediate vicinity. For forensic anthropology, this discovery allows hair that is recovered from a body to be analyzed for isotope ratios to determine where the decedent was living immediately prior to death (next to the scalp) as well as where the decedent was living years before death (depending on the length of the hair). This has helped identify countless of otherwise unidentifiable victims. Similar forensic utility has been found with both stable and unstable isotope ratios (using accelerator mass spectrometry), such as FBI's investigation of the 2001 *Bacillus Anthracis* mailings [66].

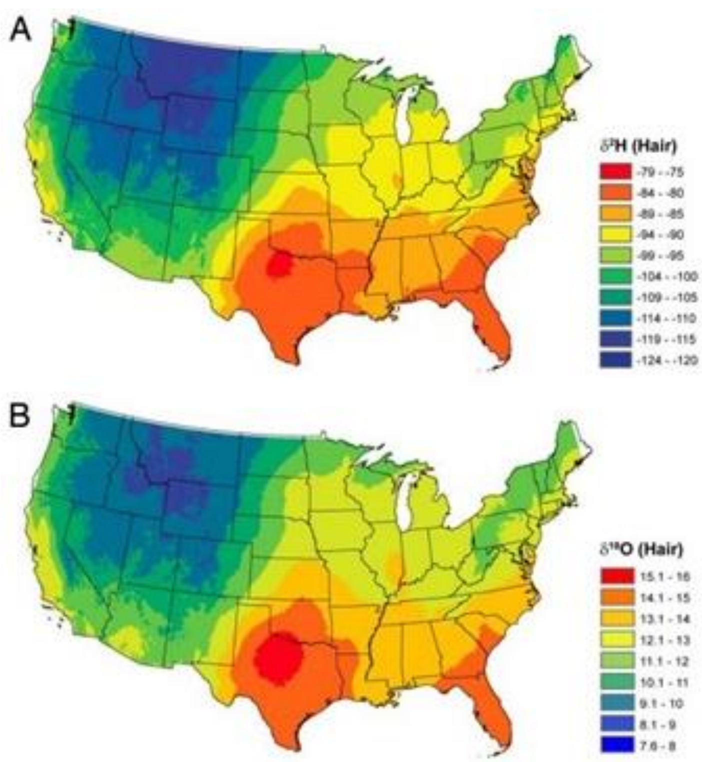

Figure 3.4.6 Geographic Information System-generated maps of (A) the predicted average H isotopes ratio and (B) the predicted average O isotopes ratio of human scalp hair across the United States. These isotope ratios can be used to identify geographic origin of unidentified human remains [65].

NUCLEAR SCIENCE IN THE MOVIES – ART AND EDUCATION WITH NUCLEAR ASTROPHYSICS

In general, the migration of physical science topics into the visual and theatrical arts is typically limited by the perception of what the viewing public will understand, especially when it comes to the topics like nuclear science. It is important to remember, however, the influence theatrical arts have on exciting the next generation of students about topics that are portrayed as interesting. To this end, nuclear science has done reasonably well in providing topics of interest to science fiction authors and screenwriters, basically because nuclear astrophysics provides startling visual material that both excites and interests most viewers. One relevant example of leveraging artistic creativity with nuclear science and even particle physics is the recent release of “Interstellar”, a popular movie distributed in the U.S. in 2014 by Paramount Pictures and Warner Brothers. It features a high degree of technical scientific accuracy, both heroes and villains as role models who are described as physicists and engineers, and a simultaneous co-release of a 300-page book [67] that explains the science behind the movie’s premise by Dr. Kip Thorne. This movie has already earned more than $650 million at the box office, holds the title as the largest grossing box office release yet for IMAX films, and while never reaching a #1 ranking of movies in the U.S. during its release, it is already one of the top grossing films of all time in many Asian markets such as China, South Korea, etc. where science and science fiction remain more popular. While it will be difficult to prove, there may be more students considering careers in nuclear science as a result of this movie than any other activity performed in 2014.

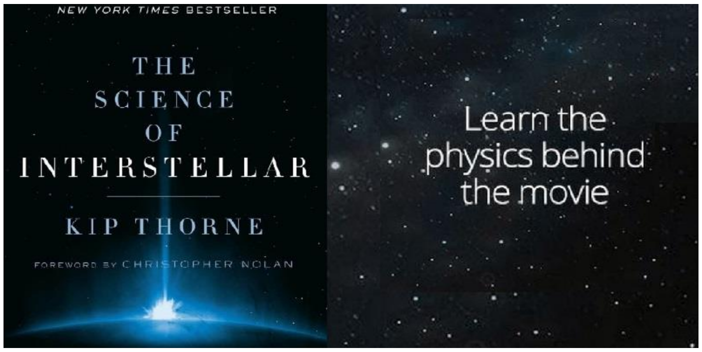

Figure 3.4.7 Advertisement for the book to accompany the movie “Interstellar” [67]

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APPENDIX A: Town Meeting Program

2014 DNP/LRP Town Meeting on Education and Innovation
National Superconducting Cyclotron Laboratory (NSCL)
6-8 August 2014

Wednesday, 6 August 2014

7:00 PM	Welcome Reception - NSCL Atrium	

Thursday, 7 August 2014

8:30 AM	*Breakfast*	
9:00 AM	**Plenary Session** - NSCL Lecture Hall	
	Introduction and Overview	Michael Thoennessen (MSU)
	Remarks by DOE	Jehanne Gillo (DOE)
	Remarks by NSF	Brad Keister (NSF)
	NSAC report on workforce development	Jolie Cizewski (Rutgers)
10:30 AM	*Break*	
10:45 AM	**Plenary Session** - NSCL Lecture Hall	
	● ***Workforce Development***	
	Analysis of workforce demographics	Michael Thoennessen (MSU)
	NNSA Workforce Development	Sean Liddick (MSU)
	The future MARS program at FIU	Joerg Reinhold (FIU)
	Educational aspects of the FRIB theory center	Filomena Nunes (MSU)
	Workforce development in computational nuclear physics	Richard Furnstahl (OSU)
12:00 PM	*Lunch*	
	Parallel Sessions	
1:15 PM	**Education** - NSCL Lecture Hall	**Innovation** - 1221A/B
	● ***Graduate Education***	● ***Defense and Security***
2:30 PM	*Break*	
2:45 PM	**Education** - NSCL Lecture Hall	**Innovation** - 1221A/B
	● ***Undergraduate Education***	● ***Energy and Climate***
4:00 PM	*Break*	
4:15 PM	**Education** - NSCL Lecture Hall	**Innovation** - 1221A/B
	● ***K12***	● ***Health and Medicine***
5:30 PM	*Break*	
6:00 PM	*Dinner* - NSCL Atrium	
7:30 PM	**Parallel discussions on draft recommendations**	

Friday, 8 August 2014

8:30 AM	*Breakfast*	
9:00 AM	**Education** - NSCL Lecture Hall	**Innovation** - 1221A/B
	• **Public Outreach**	• **Innovation, Art and Forensic**
10:15 AM	*Break*	
10:30 AM	**Plenary Session** - NSCL Lecture Hall	
	Summary discussions of recommendations	
12:00 PM	*Adjourn*	

Parallel Sessions Education

● ***Graduate Education***, Chair: Gunther Roland (MIT)

MOOC technology and nuclear physics graduate student training	Gunther Roland (MIT)
A TALENT'ed workshop model	Richard Cyburt (MSU)
Experience from the jet collaboration	Abhijit Majumder (Wayne State)
Topical collaboration TORUS and education	Filomena Nunes (MSU)
Increasing diversity	Paul Gueye (NSBP)
Fisk/Vanderbilt bridge program	David Ernst (Vanderbilt)
National nuclear physics summer school	Wouter Deconinck (William & Mary) slides provided - not presented

● ***Undergraduate Education***, Chair: Mike Snow (Indiana)

The Conference Experience for Undergraduates, a capstone for undergraduate research in nuclear science	Warren Rogers (Westmont)
Brief overview of the National Nuclear Chemistry Summer School and the National Nuclear Forensics Summer School	David Robertson (Missouri)
A nuclear physics summer school at MSU	Artemis Spyrou (MSU)
The MoNA collaboration and undergraduate education	Paul DeYoung (Hope)
The Advanced Nuclear Science Education Lab (ANSEL) at the University of Rochester	Udo Schroeder (Rochester)
Research opportunities for undergraduate students at Howard	Marcus Alfred (Howard)
An idea for online course offerings in nuclear science	Graham Peaslee (Hope)

● ***K12***, Chair: Calvin Howell (Duke)

The physics and engineering pipeline, K-12 and the nuclear physics community	Paul Cottle (FSU)
Nuclear science education related to underground science and engineering.	Peggy Norris (SURF)
K-12 diversity pipeline	Micha Kilburn (Notre Dame)
RET from a teacher perspective	Kevin Johnston (Jimtown HS)

● **Public Outreach**, Chair: Micha Kilburn (Notre Dame)

Video presentation: Outreach at JLAB	Kandice Carter (JLAB)
NSCL/JINA Outreach	Zach Constan (MSU)
ARUNA Outreach	Umesh Garg (Notre Dame)
The Contemporary Physics Education Project - Future steps	Howard Matis (LBL)

Parallel Sessions Innovation

● **Defense and Security**, Chair: Anna Hayes (LANL)

Overview	Anna Hayes (LANL)
Alternative methods of neutron detection	Graham Peaslee for Marian Jandel (LANL)
Applied research at TUNL for Homeland Security	Henry Weller (TUNL)
Application of nuclear physics of National Security	Dennis McNabb (LLNL)
Cosmic ray radiography of the damaged cores at Fukushima	Chris Morris (LANL)
Nuclear Data: Defense & Security	Anna Hayes for NNDC

● **Energy and Climate**, Chair: Ed Hartouni (LLNL)

Overview	Ed Hartouni (LLNL)
Nuclear Data: Energy & Security	Ed Hartouni for NNDC
Uncertainty quantification in fission cross section and fragment distribution measurements at LANSCE	Ed Hartouni for Fredrik Tovesson (LANL)
Decay Heat and Nuclear Data Needs	Ed Hartouni for Filip Kondev (ANL)
Nuclear power industry needs	Ed Hartouni for Ward Rigot (Cook Power Plant)
Plant research with radioisotopes	Calvin Howell (Duke)
Nuclear batteries	David Robertson (Missouri)

● **Health and Medicine**, Chair: Cynthia Keppel (JLAB)

Proton therapy at Massachusetts General Hospital	Jay Flanz (Mass General)
Proton therapy developments over the last and next decade	Jay Flanz for Niek Schreuder (ProVision)
Radioisotope production	Graham Peaslee for Amanda Johnsen (Penn State)
Innovation in medical imaging	Drew Weisenberger for Gordon Cates (Virginia)
Nuclear physics detector instrumentation as a source of advances for nuclear medicine	Drew Weisenberger (JLAB), also for Paul Vaska (BNL)
Nuclear Data: Health & Medicine	David Brown and Elizabeth McCutchan (BNL) slides provided - not presented

● **Innovation, Art and Forensic**, Chair: David Robertson (Missouri)

Isotope harvesting at FRIB	Graham Peaslee (Hope)
LANL's Isotope Production Facility	Graham Peaslee for Eva Birnbaum (LANL)
Nuclear Physics Needs for Stockpile Stewardship Applications	Graham Peaslee for Mark Stoyer (LLNL)
Trends and Applications for MeV Electrostatic Ion Beam Accelerators	Graham Peaslee for Mike Mores (NEC)
Ion Beam Applications at the Michigan Ion Beam Laboratory (MIBL)	Elizabeth Getto (Michigan)
Ion beam analysis & consumer products	Graham Peaslee (Hope)

APPENDIX B: LIST OF PARTICIPANTS

Marcus Alfred	Howard University
Ani Aprahamian	University of Notre Dame
Robert Atcher	Los Alamos National Laboratory
Eva Birnbaum[*]	Los Alamos National Laboratory
David Brown[#]	Brookhaven National Laboratory
Edward Brown	Michigan State University
Helen Caines[#]	Yale University
Kandice Carter[$]	Thomas Jefferson National Accelerator Facility
Gordon Cates[*]	University of Virginia
Zbigniew Chajecki	Michigan State University
Jolie Cizewski	Rutgers University
Zachary Constan	Michigan State University
Paul Cottle	Florida State University
Richard Cyburt	Michigan State University
Wouter Deconinck[*]	College of William & Mary
Paul DeYoung	Hope College
David Ernst	Vanderbilt and Fisk Universities
Jay Flanz	Massachusetts General Hospital
Richard Furnstahl	Ohio State University
Umesh Garg	University of Notre Dame
Konrad Gelbke	Michigan State University
Elizabeth Getto	University of Michigan
Jehanne Gillo	Department of Energy, Office of Science
Thomas Glasmacher	Michigan State University
Paul Gueye	National Society of Black Physicists
Ed Hartouni	Lawrence Livermore National Laboratory
Anna Hayes	Los Alamos National Laboratory
Jerry Hinnefeld	Indiana University at South Bend
Calvin Howell	Duke University and TUNL
Marian Jandel[*]	Los Alamos National Laboratory
Amanda Johnsen[*]	Pennsylvania State University
Kevin Johnston	Baugo Community Schools
Bradley Keister	National Science Foundation
Cynthia Keppel	Thomas Jefferson National Accelerator Facility
Micha Kilburn	University of Notre Dame
Zach Kohley	Michigan State University
Filip Kondev[*]	Argonne National Laboratory

Anthony Kuchera	Michigan State University
Sean Liddick	Michigan State University
Abhijit Majumder	Wayne State University
Yousef Makdisi#	Brookhaven National Laboratory
Paul Mantica	Michigan State University
Howard Matis	Lawrence Berkeley National Laboratory
Dennis McNabb	Lawrence Livermore National Laboratory
Mike Mores*	National Electrostatics Corporation
Christopher Morris	Los Alamos National Laboratory
Peggy Norris	Black Hills State University and Sanford Underground Research Facility
Filomena Nunes	Michigan State University
Graham Peaslee	Hope College
Scott Pratt	Michigan State University
Joerg Reinhold	Florida International University
Elizabeth Ricard-McCutchan#	Brookhaven National Laboratory
Ward Rigot*	Cook Power Plant
J David Robertson	University of Missouri at Columbia
Warren F. Rogers	Westmont College
Gunther Roland	Massachusetts Institute of Technology
Niek Schreuder*	Provision Center for Proton Therapy
Udo Schroeder	University of Rochester
William Snow	Indiana University
Lee Sobotka#	Washington University
Artemis Spyrou	Michigan State University
Mark Stoyer*	Lawrence Livermore National Laboratory
Michael Thoennessen	Michigan State University
Fredrik Tovesson*	Los Alamos National Laboratory
Betty Tsang	Michigan State University
Chun Yuen Tsang	Chinese University of Hong Kong
Paul Vaska*	Brookhaven National Laboratory
Drew Weisenberger	Thomas Jefferson National Accelerator Facility
Henry Weller	Duke University and TUNL
Michael Wiescher	University of Notre Dame
Jack Winkelbauer	Michigan State University

*Submitted contribution to the town meeting
#Participated via webinar
$Presented contribution via webinar

APPENDIX C: PRESENTATION ABSTRACTS

NSAC Report on workforce development

Jolie A. Cizewski, Rutgers University

The Nuclear Science Advisory Committee was charged to identify disciplines that need additional workforce training at graduate and postdoctoral levels to realize the missions of the Department of Energy (DOE) Office of Science (SC) and to make recommendations to address these discipline-specific workforce development needs. The report [1] was submitted to DOE on July 18, 2014. The workforce development report identified challenges in attracting and training the nuclear scientists at all stages of their careers, from U.S. school students to early career leaders. It also identified the sub-disciplines of nuclear and radiochemistry, accelerator science and technology, and high-performance computational nuclear science and technologies as areas where enhanced workforce development activities were needed since these are under-represented at universities (as is the case for fundamental nuclear science as well). Of critical importance is sustaining the Nuclear Chemistry Summer Schools that have been an essential component in introducing future leaders to this field yet the funding for this program has ended.

The recommendations span the stages in education and training of nuclear scientists. The workforce development has to start with outreach to school students and their teachers and from diverse backgrounds. Introducing undergraduate students to nuclear science studies and in particular engaging them in research is a task that many of us excel in. Graduate students and postdocs should have an expanded introduction to the multi-disciplinary science and technologies that characterize research at the DOE laboratories. And students, postdocs and early career scientists should be recognized for their excellence in research and potential for leadership. This includes the recommending that mentors of undergraduates help them develop competitive proposals for external fellowships. To assess the effectiveness of these programs, the report recommended that the DOE/SC Office for Workforce Development for Teachers and Students (WDTS) be responsible for collecting data on the participants in these programs, in particular the Science Undergraduate Laboratory Internship (SULI) program, to assess their effectiveness and with an ongoing effort to analyze the DOE's (and nation's) needs for a diverse and talented science and technology workforce.

[1] http://science.energy.gov/~/media/np/nsac/pdf/docs/2014/NSAC_workforce_jul-18-2014.pdf

[2] http://science.energy.gov/~/media/np/nsac/pdf/docs/2013/NSAC_FacilitiesReport.pdf

Analysis of workforce demographics

Michael Thoennessen, Michigan State University

The development of the general nuclear workforce is an important part of the nuclear scientific community. The number Ph.D.'s awarded in fundamental nuclear science has been fairly constant with about 80-100 per year. While about 40% stay in academia a large fraction begin careers in business/industry and National Laboratories (~50%).

While the basic statistics of Ph.D.'s per year is compiled by the AIP [1], DOE [2], and NSF [3], more detailed information about the career paths require more extensive surveys. A recent search of departmental websites extracted the distribution of "Year of Ph.D." of current nuclear science faculty at U.S. major research institutions. A yearly update of this information can reveal any emerging trends of retirements and new hires.

In order for any these statistics and surveys to be representative it is important that all data are reported and categorized as Nuclear Science. There are indications that a significant fraction of Ph.D. theses in nuclear science are not included in the general statistics and that some departments do not list or highlight their nuclear science research on their websites.

[1] http://www.aip.org/sites/default/files/statistics/graduate/trendsphds-p-12.2.pdf
[2] http://science.energy.gov/~/media/np/pdf/Workforce_Survey_Report_2013.pdf
[3] http://www.nsf.gov/statistics/sed/2012/data_table.cfm

NNSA workforce development

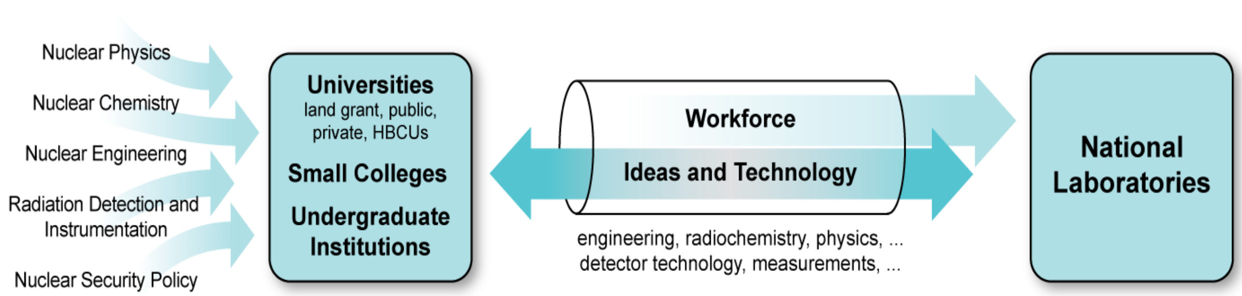
Sean Liddick, Michigan State University

Low-energy nuclear science addresses many open questions in forefront science including how elements are created and the origin of simple patterns in complex nuclei. In addition, low-energy nuclear science plays a critical role for the nation through stockpile stewardship, homeland security, nuclear forensics and the development of the next generation of nuclear reactors. Despite the importance of nuclear science to the welfare of the nation, numerous reports highlight a deficiency in the current workforce. The most recent example, from the Assessment of Workforce Development Needs in the Office of Nuclear Physics Research Discipline, highlights the difficulty of recruiting qualified individuals trained in nuclear science for the national laboratories and documents nuclear physics as a declining percentage of subfields for U.S. physics PhD students.

The National Nuclear Security Administration (NNSA) has made substantial investments in basic low-energy nuclear science research to develop a highly trained workforce. An example of two such programs include the Stewardship Science Academic Alliances (SSAA) and the more recent National Nuclear Security Consortium (NSSC) led by University of California-Berkeley. The pursuit of cutting edge science attracts the best and brightest students and postdocs and, when combined with national laboratory participation, establishes a career pathway of trained individuals for nuclear science positions at the national laboratories.

The NSSC brings together a broad group of disciplines including nuclear physics, chemistry, and policy in which students have a wide variety of exposures to nuclear science problems addressing national priorities from class work to dedicated summer schools.

Within the SSAA, the Center for Radioactive Ion Beam Studies for Stewardship Science (RIBSS) brings together a group of researchers to understand the properties and decay of and reactions on fission fragments. A key feature of the RIBSS Center is immersing students in the national laboratory environment by siting them for a summer at either Livermore or Los Alamos NNSA laboratories. The SSAA also supports individual investigator projects and the Stewardship Science Graduate Research Fellowships. PhD alumni from all of these NNSA-supported opportunities have careers in academia, national laboratories and industry.



Schematic pipeline from universities to national laboratories.

The future MARS program at FIU

Joerg Reinhold, Florida International University

The Department of Physics at Florida International University (FIU) is developing a Master's program in Applied Radiological Sciences (MARS). One of the goals is to increase nuclear science research and education at FIU. The curricula development for radiation physics, nuclear measurements and radiochemistry has been funded by the U.S. Nuclear Regulatory (NRC) and includes classes and labs in radiochemistry, nuclear radiation detection and measurement, radiation physics and dosimetry and radiation safety.

The first course in radiochemistry was taught to a diverse group of 21 students from chemistry, biology, physics, and biomedical engineering. In the fall of 2013. In the fall of 2014 courses and labs in radiochemistry and radiation detection and measurement will be offered.

Scholarships and Fellowships funder by the NRS are available to undergraduate and graduate students. A full proposal for MARS will be submitted in the fall of 2014 and the program is expected to start in 2016.

Educational aspects of the FRIB theory center

Filomena Nunes, Michigan State University

Advances in theory provide the essential underpinning to understanding nuclei and their role in the cosmos. As for other facilities, a theory center associated with FRIB is critical to fulfill its role in answering the science questions that FRIB will address. An FRIB theory center steering committee was created with the goal of determining the required ingredients, including ramp-up funding options and an appropriate organizational structure for a future FRIB theory center. The proposed FRIB Theory Center contain two national initiatives, namely the National FRIB theory fellow program and the Faculty Bridge Program. In addition, a coordinated educational effort is planned. The FRIB theory center will be a key ingredient to the success of the science at the Facility for Rare Isotopes (FRIB) by continuously updating its intellectual framework; optimizing the coupling between theory and experiment; rejuvenating the field by creating permanent positions across the country; attracting young talent through the national FRIB theory fellow program; fostering interdisciplinary collaborations; and shepherding international initiatives.

Workforce development in computational nuclear physics

Richard Furnstahl, Ohio State University

Realizing the scientific potential of current and future experiments demands large-scale computations in nuclear theory that exploit the US leadership in high-performance computing (HPC). This in turn requires a multi-disciplinary workforce. As summarized in the 2013 Tribble Committee Report on Implementing the 2007 Long-Range Plan: "... early-career scientists working at the interface between nuclear theory, computer science, and applied mathematics are critical to make future impact, especially in the era of extreme computing that demands the novel coding paradigms and algorithmic developments required by novel architectures." These needs are echoed in recent workforce reports from ASCAC, NSAC, and HEPAP. To address these needs, investment is required in innovative education and training, including summer schools; CSGF-type fellowships and more generally partnerships between ACSR, labs, and universities to train jointly in physics and computation; and increased funding of nuclear physics in SciDAC.

The NP community is well-positioned to build on existing strengths to take the lead in supporting experimental, National Laboratory, and societal needs based on HPC. To this end the Computational Nuclear Physics community recommends the creation of an NSAC subcommittee to plan a diverse program of new investments in computational nuclear theory.

MOOC technology and nuclear physics graduate student training

Iain Stewart and Gunther Roland, Massachusetts Institute of Technology

Large resources are being invested in the development of online/digital learning frameworks by private companies and University consortiums, such as edX. These are primarily designed to deliver Massive Online Open Courses (MOOC's) to large audiences world-wide. The same technology can be employed to solve an otherwise intractable problem in graduate education: Highly specialized material, that is nevertheless fundamental to the training of students in their theoretical or experimental field of expertise, is economically impractical to deliver to the small number of students entering a given research regroup per year in a traditional lecture course format. Furthermore, local expertise may not be available, in particular in smaller departments, to provide training in all aspects of a rounded grad student or undergraduate student education in essential areas of nuclear physics.

MOOC technology can be used to provide an effective education in face of this sparseness of the student population in time and geography. It may not be feasible for a research group to provide a live lecture course in their specialty for 1 or two students joining per year, but if such material is provided within an online framework it can be shared, maintained and further development by a wider community over time and at different locations, eventually serving hundreds (or more students) over time and nation- or world-wide. The use of MOOC technology allows to flip the class-room, by having the students work on the online material and then use face time with fellow students, mentors and advisors most efficiently.

Two graduate level efforts using edX technology are currently underway at MIT, with support from the MIT Office of Digital Learning and the Office of the Dean of Graduate education. 8.EFTx is an online course on effective field theory by Prof. Iain Stewart that went live in Fall 2014 and reached an initial enrollment of close to 3000 students (web.mit.edu/eftx). 8.SHIP takes a different approach, providing a hierarchical set of short seminar-style lectures introducing students to the physics of relativistic heavy ions and the quark-gluon plasma, from an outreach/colloquium level introduction to 3-5min micro-lectures provided by students and postdocs on the latest developments in theory and data analysis.

These efforts require significant initial investment and therefore buy-in from the wider community for pay-off and sustainability. If successful, they should serve as prototypes for different subfields within nuclear physics and elsewhere.

A TALENT'ed workshop model

Richard Cyburt, Michigan State University

The Training in Advanced Low Energy Nuclear Theory (TALENT) Initiative was created to provide advanced and comprehensive training to graduate students and young researchers across the many disciplines of nuclear theory. TALENT members, organizational and participatory, represent many institutions worldwide showing the widespread interest in the initiative. The aim of the TALENT Initiative is to develop a broad curriculum in cutting-edge nuclear theory in order to understand nuclei, nuclear reactions, astrophysics and more. To meet this aim, learning material is generated via 9 topical courses encompassing the many realms of nuclear theory, including nuclear theory needed for experiments and astrophysics. These courses utilize active learning techniques and involve cooperative student projects.

All schools have been over-subscribed with high-quality applicants, with very positive feedback from students (via post-course surveys). Issues under consideration for the next phase of the TALENT Initiative involve cycling through the topical programs with new/updated versions, including a remote participation presence, disseminating course materials (technologies, repositories) and expanding participation and venues outside North America and Europe. TALENT relies on volunteers and institutions to support its programs, however an outlying question remains about the long-term support and credit-awarding power of the Initiative. The FRIB Theory Center would be a natural facilitator for this effort.

Topical collaborations in nuclear theory and graduate education

Abhijit Majumder, Wayne State University

Nuclear theory topical collaborations, such as the JET collaboration were recommended in the 2007 Long range plan. These are 5 year, fixed term multi-institution collaborations set up to find solutions to targeted problems in nuclear theory that require multiple types of expertise. The JET collaboration at the time of its inception had 9 institutions and has, over time, supported graduate students at several of these institutions. While making tremendous progress in nuclear theory research, the JET collaboration also had a substantial influence on graduate education. The primary influence was on the many graduate students working on JET projects. Via the platform of in-person and remote collaboration meetings, these students were exposed to a variety of experts, and to different aspects of heavy-ion collisions. They both reported on their work and collaborated with peers and experts at distant institutions. This has led to a much more holistic education experience which would not have been possible in a single PI or local group setup. Beyond this, annual summer schools and workshops held by the JET collaboration have led to a broad dissemination of the knowhow relating to jet quenching and hydro-dynamic calculations to an audience of students far beyond the purview of the JET collaboration. These along with the successful migration of graduate students to postdoctoral positions, bears evidence for the positive influence of topical collaborations on graduate education.

Topical collaboration TORUS and education

Filomena Nunes, Michigan State University

The primary mission of the topical collaboration on Theory Of Reactions with Unstable isotopes (TORUS) is to develop new methods that will advance nuclear reaction theory for unstable isotopes by using three-body techniques to improve direct-reaction calculations. It involves two national laboratories (Thompson and Escher at LLNL and Arbanas at ORNL) and two universities (Elster at OhioU and Nunes at MSU). It provided funding for one postdoc and for the initial 3 years this postdoc was located at MSU (N. Upadhyay) and is now at OhioU (V. Eremenko). A supplement funding was found for a student in the 4th year (Hlophe at OhioU). Although some of the members of the collaboration had previously collaborated on other projects, it is clear that the ambitious longterm project of the TORUS collaboration would have not taken place if a topical collaboration had not been formed. Moreover, although the collaboration was modest in funding, it enabled the interaction of the research groups associated with the collaboration, providing a richer intellectual environment to the various students working with Nunes and Elster. In this way, efforts were largely leveraged.

Increasing diversity

Paul Gueye, National Association of Black Physicists

The recent alarming trend of physics departments closing or merging (with other science disciplines and/or engineering departments) at Historically Black Colleges and Universities (HBCUs) (from 36 in the early 2000s down to 30 in 2014) is having a dramatic impact on the already very low number of African American graduating with an MS or PhD in physics (2-3%). Minority Serving Institutions (MSIs), especially HBCUs, have historically been the leading institutions to grant BS degrees in physics to African-Americans who go on to obtain a MS and/or PhD degrees in physics: NSF statistics show that about 20-25% of Black physics doctorates get their starts at HBCUs. Hence these institutions must build solid educational foundations for future graduate students, as well as nurture graduate programs that are struggling to provide students with the necessary tools that will enable them to be competitive in the workforce.

The nuclear science community can play a vital leading role for the physics and scientific communities in increasing the number of under-represented users within national facilities and assisting in developing university-based laboratories at MSIs. The primary impediment for MSIs are the limited or lack of access to equipment and infrastructure due to funding to expose students to forefront research; however they provide a unique environment for students with a major focus on mentoring that has proven to be a key factor for students' success: a large fraction comes to the undergraduate level with poor high school backgrounds that often cannot be served by most majority institutions.

A sustainable pipeline of minority nuclear scientists means that they must be sustained in the long-term by the same programs that sustain majority programs to address competitive research and educational opportunities. Increasing collaborations among MSIs, majority-serving institutions, industries and government facilities could result in collaborative proposals to federal and non-federal agencies. This would increase research opportunities in nuclear science and associated technologies for students and faculty from underrepresented groups. Academic, federal and private organizations should establish new, or sustain existing partnerships and collaborations, with institutions and professional organizations serving underrepresented groups, such as the National Society of Black Physicists (NSBP, www.nsbp.org) and the Interdisciplinary Consortium for Research and Educational Access in Science and Engineering (INCREASE, www.increaseonline.org). These relationships can be fostered in two ways: 1.) Support and attendance at the NSBP Annual Conference; 2.) The nuclear science community should also establish dedicated (summer and/or year-long) training programs in the nuclear sciences geared specifically towards increasing under-represented groups. These programs should focus on developing skills, retention, and developing collaborative research with the student's home institution and other HBCUs.

Race and Ethnicity of Exiting Physics Master's, Classes of 2010, 2011 & 2012 Combined.

	3-Yr Average Number	Percent* of all Physics Master's	Percent of U.S. Physics Master's**
White	450	58	86
Asian American	26	3	5
Hispanic American	27	3	5
African American	18	2	3
Other U.S. Citizens	6	1	1
Non-U.S. Citizens	250	32	-
Total	777	100%	100%

Race and Ethnicity of Physics PhDs, Classes of 2010 through 2012.

	3-Year Average Number	Percent of all Physics PhDs	Percent of U.S. Physics PhDs*
White	744	45	88
Asian American	41	2	5
Hispanic American	28	2	3
African American	17	1	2
Other U.S. Citizens	13	1	2
Non-U.S. Citizens	826	49	-
Total	1,669	100%	100%

Source: AIP Statistical Research Center (aip.org/statistics)

Fisk/Vanderbilt bridge program

David Ernst, Vanderbilt University

The under-representation of minorities in physics is a major issue that needs to be broadly addressed. The leakiest point in the pipe line is the transition from the bachelor degree to the PhD degree. Bridge programs have proven to be effective at increasing the number of students successfully making this transition and continuing on for the PhD. Support from government agencies for this and other efforts to enhance diversity in nuclear physics need to be increased.

National Nuclear Physics Summer School

Wouter Deconinck, College of William & Mary

To address deficiencies and gaps in the nuclear physics graduate education at many small and medium size institutions (which have specialized in one of the subfields of nuclear physics), the National Nuclear Physics Summer School (NNPSS) is organized yearly for about 50 advanced graduate students and junior researchers. Host institutions are selected by the steering committee through a proposal process, and financial support is provided by National Science Foundation through the Institute for Nuclear Theory.

At the most recent NNPSS in 2014, approximately one third of the participants were postdoctoral researchers and two thirds were graduate students. The summer school's international appeal is demonstrated by one third participation from foreign institutions. For domestic participants downward pressures on research grants of individual PIs appear to be limiting the ability of participants to travel, in particular for participants from smaller institutions. An increase in travel support for participants will ensure the continued success in reaching participants who may benefit most from the breadth that this program offers.

Conference Experience for Undergraduates

Warren Rogers, Westmont College

The nuclear science community has been very effective at involving undergraduate students in research, assisted by NSF and DOE programs such as Research Experience for Undergraduates (REU), Research at Undergraduate Institutions (RUI), Science Undergraduate Laboratory Internships (SULI), and DOE university grants, among others. Research experiences for undergraduate students significantly enhance their undergraduate educational experience, expose them to modern laboratory science practice and methodology, and play a potentially pivotal role in shaping future career decisions.

The Conference Experience for Undergraduates (CEU) was designed specifically to enable student researchers to bring their efforts to full fruition by presenting their work to the professional nuclear science community at a national conference. The CEU provides the logical capstone for their experience, and in the process exposes them firsthand to the excitement of the field and the human face of the community.

The CEU has been held concurrently with the past 17 consecutive Fall DNP meetings, and has brought over 1500 American and 40 Japanese undergraduate students who have conducted research in nuclear physics to the national meetings.

Funding for the conference has been provided by the National Science Foundation and the Department of Energy (through the national accelerator laboratories) and the APS Division of Nuclear Physics. The CEU draws applications from students around the country and abroad. Their application materials are reviewed by an independent review committee, and travel and lodging grants are awarded based on project merit. Students who don't receive awards are often able to participate based on assistance from their research advisers or home institutions. For most, participation in the DNP meeting represents their first professional conference experience and the first opportunity to present their research to a broad professional audience.

Several specific CEU activities are organized for the students as part of their conference experience, including two nuclear physics seminars directed at an advanced undergraduate level on topics of broad and current interest in the field of nuclear science, a social event where they also have opportunity to meet with several members in DNP leadership, a research poster session that is probably the best attended event following the plenary session talks, and a graduate school information fair where students can learn about a number of graduate school opportunities in nuclear science. A presentation on graduate school application advice and tips has also been added in recent years.

Survey and anecdotal data indicate several benefits of CEU participation, including an increased interest in the field of nuclear science and in the prospect of attending graduate school in physics. Students discover that scientists are genuinely interested in their research, that is, that their work is valued and highly relevant to the field as a whole. They meet peers, graduate students, and established scientists who share a common interest and bond in physics and research, and many students catch an inspiring vision of a future in nuclear science. They see first-hand how fundamental communication and sharing of ideas occurs among professional scientists. They have a unique opportunity to discuss graduate school opportunities with scientists from several top institutions and laboratories. Each of these benefits serves to strengthen retention of talented students in nuclear science. Finally, the entire nuclear science community benefits from the energy and excitement these bright young scientists bring to the meeting.

The Nuclear Chemistry Summer School Program

David Robertson, University of Missouri

Since the 1940s our nation recognized the strategic need for research and training in nuclear science, nuclear chemistry and radiochemistry. These disciplines are essential to the foundation of many 21st century technologies including energy production in the context of carbon dioxide abatement, the development of nuclear medicine and radiopharmaceuticals, technologies that probe the structure and properties of materials, and national security.

Although the subjects of nuclear chemistry and radiochemistry were once prominent in the undergraduate curricula of most US colleges and universities, these courses have slowly disappeared at many academic institutions due to faculty retirements and reductions in research funding in these areas. The manpower shortage that resulted, was first described in a 1988 National Research Council (NRC) report "*Training Requirements for Chemists in Nuclear Medicine, Nuclear Industry, and Related Areas.*" The report stated "*…The future vigor and prosperity of American medicine, science, technology, and national defense clearly depend on continued development of nuclear techniques and use of radioactive materials. Loss of know-how in the field or failure to develop new uses for the technology could seriously and adversely affect this country's economic competitiveness in many technological and industrial areas…*" Recently, this issue was revisited in the 2012 NRC report "*Assuring a Future US-Based Nuclear and Radiochemistry Expertise*". The 2012 NRC report emphasizes that "*the needs for nuclear and radiochemistry expertise are barely being met by current supply and that future needs may not be met by the supply projected given current trends.*"

One of the principal reasons given for the current and projected shortage is that "*there is little nuclear and radiochemistry taught at the undergraduate and graduate level.*" Further the report "*commended current and past efforts of federal agencies to support nuclear and radiochemistry workforce education*" and training citing the "*DOE-sponsored SSNR as an excellent example of [a program that has] helped supplement inadequacies in undergraduate education.*" The SSNR is an intensive 6-week undergraduate fellowship program designed to introduce nuclear and radiochemical concepts through lecture and laboratory experiments to outstanding upper level undergraduate science and engineering majors and to stimulate their interest to pursue graduate studies in the field. Although the SSNR targets undergraduates, it has served as a critical pathway for filling the graduate student pipeline to develop and train the next general of nuclear and radiochemists!

For three decades, the DOE has funded the SSNR. Since they were first introduced in 1984, the Summer Schools have successfully introduced 651 of this nation's best and brightest undergraduate students to nuclear and radiochemistry and provided information on summer internships at national laboratories, graduate education, and career paths in these fields. Nearly 20% of all the Summer School participants have gone on to pursue careers in the nuclear sciences and many of these individuals are now in a position to influence other young people to enter the field. The impact and importance of the Summer Schools on graduate and postdoc workforce training in this area is highlighted by the fact that approximately half of the 15 to 20 nuclear chemistry and radiochemistry Ph.D. degrees now awarded annually in the United States are to individuals who were introduced to the field through the Summer Schools in Nuclear and Radiochemistry!

A nuclear physics summer school at MSU

Artemis Spyrou, Michigan State University

As presented in the 2004 NSAC report on Education in Nuclear Science, a significant number of undergraduate programs in the US do not offer a nuclear physics course at all, and about half of them offer a combined nuclear/particle physics class. The report emphasized the need to attract more students in nuclear science and one of their recommendations was the addition of more nuclear science summer schools. Such a summer school that focuses on introducing Nuclear Science to undergraduate students was funded by the NSF through a CAREER award.

The summer school is funded to run for four years (2016-2019) and it will be hosted at Michigan State University. It will include nuclear science lectures, hands-on activities and research discussions with researchers at the National Superconducting Cyclotron Lab. 12 students will be able to participate each year, with full travel, housing and meal support. This school will target students whose schools do not offer a nuclear physics class or lab and will give these students the opportunity to be exposed to the field of nuclear physics and consider it as a future career option.

The MoNA collaboration and undergraduate education

Paul DeYoung, Hope College

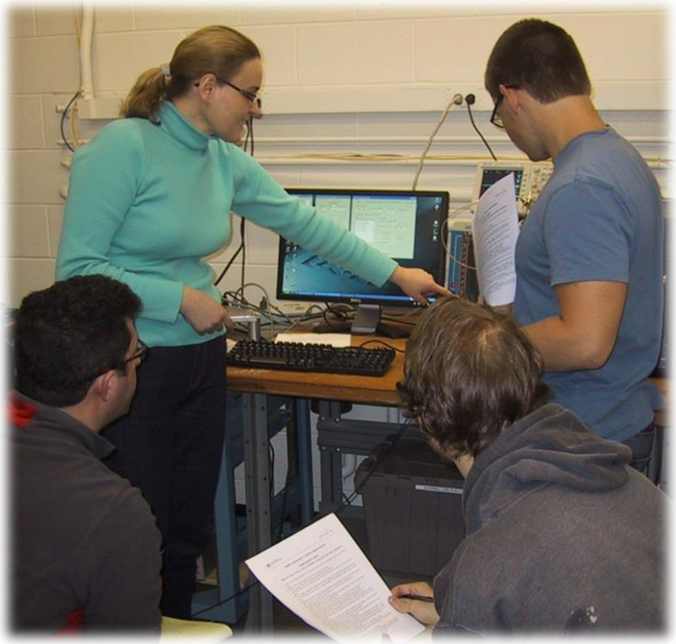
The MoNA Collaboration is a partnership of ten undergraduate institutions and the National Superconducting Cyclotron Laboratory (NSCL) studying neutron-rich unstable nuclei with the Modular Neutron Array (MoNA), the Large multi-Institutional Scintillating Array (LISA), and 4T superconducting Sweeper magnet. The collaboration is committed to producing high impact physics results while simultaneously involving and training undergraduates. To date the Collaboration has produced 37 peer reviewed publications including over 100 student coauthors. The students involved learn many basic research skills including, fitting, programming, plotting, record keeping, organization, writing, problem solving, and general experimental maturity.

Of the 140 undergraduate students that have been involved, in any way, with the MoNA Collaboration, 89% are known to be in the educational pipeline or working in a STEM field. The 126 students that are no longer at an undergraduate institution, only 5% failed to complete a degree 62% are either in a graduate program or have completed an advanced degree. The 59 students that are in the workforce are in a wide variety of careers from IT to teachers to medical areas. The percentage of women in MoNA, approximately 30%, is higher than that of all undergraduate physics students. None of the women in MoNA failed to complete their BA/BS degree and also have continued in advanced education at higher rates than all women BA/BS recipients.

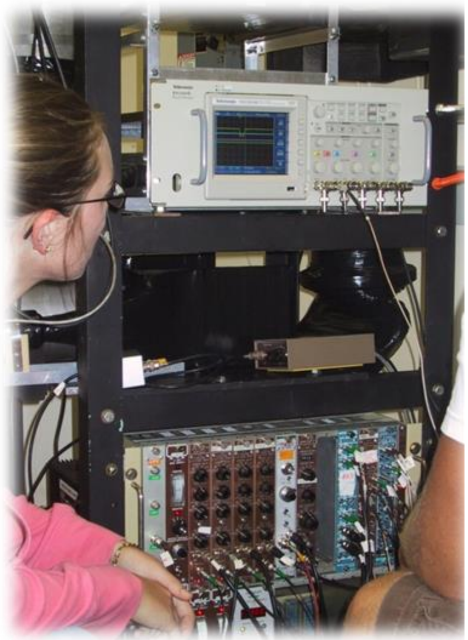
The Advanced Nuclear Science Education Lab (ANSEL)

Udo Schroeder, University of Rochester

The Advanced Nuclear Science Education Lab, recently established at the University of Rochester, is offered now every year, providing students with hands-on experience in nuclear science and technology applications. To a number of students, the ANSEL has already proven its value as gateway to a career in nuclear science.



ANSEL students group with Teaching Assistant Iwona Pawelczak



ANSEL students at the cosmic ray telescope.

Research opportunities for physics undergraduate students at Howard University

Marcus Alfred, Howard University

In light of the dismal numbers of African Americans entering and graduating from nuclear physics graduate programs, the Department of Physics and Astronomy at Howard University has begun a comprehensive program to increase these numbers. The program has included research activities, academic year stipends, academic support, and external summer internship experiences. Currently, there are 9 students in the program and all have interest in going to graduate school. Typically, the single biggest impediment to the success of physics students at Howard University has been financial support.

Online course offerings in nuclear science

Graham Peaslee, Cathy Mader, Hope College
and Con Beausang, Richmond University

The number of nuclear science course offerings at the undergraduate level has been declining rapidly, with the result that fewer students are exposed to nuclear science as undergraduates and presumably this will have the long-term effect of having fewer undergraduates enter the field. This has been noticed for years already in nuclear chemistry, but undergraduate nuclear physics courses have also been moved to alternate year offerings or merged with modern physics topics or particle physics topics as the undergraduate curriculum expands to incorporate newer areas of science. Since so much of nuclear chemistry and nuclear physics is common material at the undergraduate level, this is a proposal to treat the two similarly in an effort to broaden exposure to the field of nuclear science in general through the use of online course offerings.

Our suggestion is that online or distance education can extend course offerings to institutions that don't currently offer nuclear science education and therefore reach more students that currently don't get any exposure to nuclear science in their curriculum. As a community, we should adapted some national standards for both nuclear physics and nuclear chemistry for undergraduates, so that independent teachers could develop the materials required to provide effective online instruction in nuclear science. There are imaginative ways to integrate online education with laboratory experiences as well, which is important for student engagement.

We propose that a sequence of online and quasi-online or live web-cast courses for undergraduate nuclear science be created, ranging from very basic introductory concepts to more advanced topics that are appropriate for undergraduates in institutions that do not have regular offerings in nuclear science. These newly developed course offerings should be broken into 2 or 3 separate, smaller modules that allow students to be introduced to nuclear science early in their undergraduate career and then dig into the topic more deeply as they progress through their undergraduate program.

To accomplish this proposal, several things are required, including:

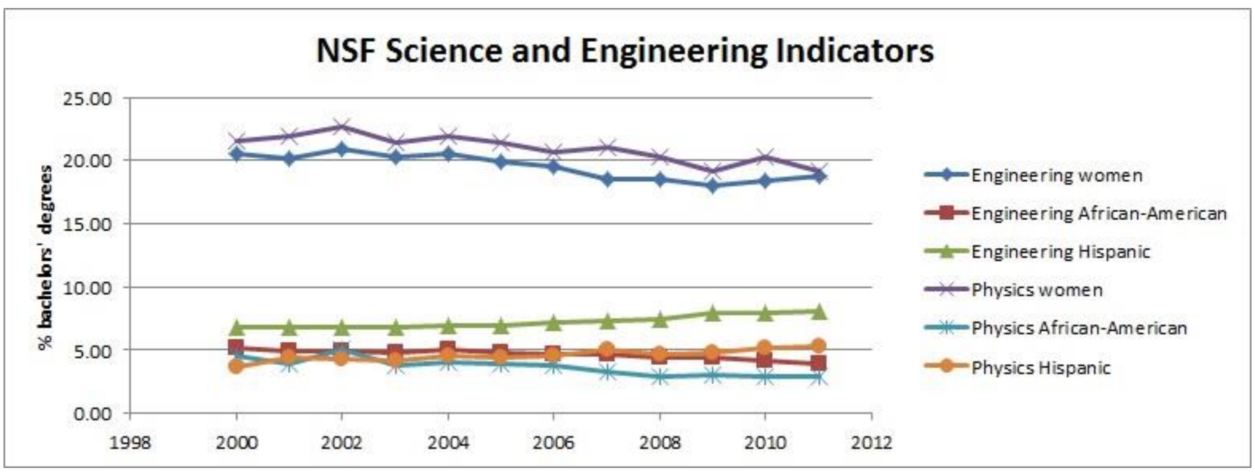
- A clear consensus from community to try…
- A team of educators to develop initial offerings…
- A consortium of host graduate institutions to provide infrastructure, credit for fee, etc.…
- A consortium of affiliated laboratories to offer experimental opportunities for cohorts…
- A coordinator or coordinating educational committee to implement, assess, fine tune…

The physics and engineering pipeline, K-12 and the nuclear physics community

Paul Cottle, Florida State University

Despite the growing reliance of the national economy on technological innovation, the production of bachelors' degrees in engineering and physics is flat over the last ten years as a percentage of total bachelor degree grads. The percentage of bachelors' degrees in engineering and physics earned by women has been stuck at about 20% for a decade. The percentage of bachelors' degrees in engineering and physics earned by African-Americans is drifting downward under 5%. The percentages of those degrees earned by Hispanics is not doing much better. Statistics from AP exams and physics course-taking in high school demonstrate that these problems originate before college – somewhere in K-12. The most promising way of addressing these compelling issues is to build relationships with students in middle school - before young women and minority students give up on math and science.

Because of its history of outreach and K-12 education, the nuclear science community is well-positioned to assume a national leadership role in addressing these issues. This community should make a publicly visible national commitment to addressing the engineering and physical science pipeline, and should begin by packaging the work it is already doing so that awareness can be raised among policy-makers and community members. Such an effort could benefit the health of the nuclear science community, including its research enterprise.



Nuclear physics provides teachable moments and future careers

Peggy McMahan Norris, Black Hills State University

The Sanford Underground Research Facility has been operating since 2009 at the site of the former Homestake Gold Mine in Lead, SD. Currently, Sanford Lab is hosting two major experiments; LUX, a direct search for dark matter, and the Majorana Demonstrator, a demonstration neutrinoless double-beta decay experiment. The experiments hosted at SURF - currently and planned for the future - are pursuing physics topics that are often hard for students to grasp. Two things they all have in common, however, is the reasoning behind locating them a mile underground (to escape cosmic rays) and the extent to which they seek to achieve the lowest possible radioactive backgrounds. This provides avenues for education and outreach staff to connect students to the science going on in their backyard, and at the same time to challenging and satisfying careers in applications of nuclear science. This talk gave examples of nuclear science activities used for audiences of K-12 students, educators, undergraduates and the general public.

The diversity pipeline from K-12 to tenure

Micha Kilburn, University of Notre Dame

Nuclear physics needs diversity in regards to race, class, & gender in order to strengthen our intellectual community. Using Maslow's Needs Hierarchy from psychology gives insight to the unmet "needs" of URM students and early researchers that act as barriers to becoming physicists. These, often invisible, barriers are responsible for the "leaky pipeline" that shows fewer percentages of URMs from graduate student to tenured faculty. Demographics data from K-12 outreach programs show that these leaks begin well before college. Studies from other STEM fields that also struggle with diversity can lend us insight about implicit bias in both recruiting and retaining URMs. Pilot programs in other fields also show that female participation can be increased by adding a focus on social or humanitarian aspects of the field. Recommendations include ensuring that outreach programs are free or sliding scale, maintaining welcoming environments while actively recruiting role models for URMs, being mindful of implicit bias in teaching, selection/hiring, and promoting from undergrad through tenure.

The lack of diversity in physics is a known problem, and yet efforts to change our demographics have only had minor effects during the last decade. Some of the hidden barriers that dissuade underrepresented minorities in becoming physicists can be explained through a framework borrowed from sociology, Maslow's Hierarchy of Needs. This hierarchy states that people must meet physiological needs (food, sleep, safety, etc.) and psychological needs (acceptance, esteem, etc.) before realizing one's full potential and being truly capable of endeavors such as creative problem solving such as that required by physics. These barriers are not unique to physics and research at the undergraduate to faculty levels over a variety of STEM fields (also seeking to recruit URMs) can provide lessons for physics. Analysis from outreach programs by the Joint Institute for Nuclear Astrophysics (JINA) can also shed light on the outlook for current K-12 students, especially female students, in becoming physicists.

RET from a teacher's perspective

Kevin Johnston, Jimtown HS

As a grateful participant of the RET (Research Experience for Teachers) program I have often tried to recruit other teachers to participate in the opportunities that this program offers. Though many will admit that the program sounds great, they will often find a variety of reasons to not participate. These can involve time constraints involving the need to work or take specific classes for their licensing. Many outreach programs address this with weekend or shortened summer programs. Though not all teachers are able or willing to avail themselves of the RET program, it still provides the atmosphere to develop on-going relationships and a sense of community between the university and K-12 community of teachers.

Outreach at JLab

Kandice Carter, Jefferson Lab

Scientists and communications professionals at the Department of Energy's Thomas Jefferson National Accelerator Facility employ a wide range of strategies and tools to advance knowledge of science and technology through education and public outreach, from classic methods, such as journal articles, public events and student mentoring, to newer methods, such as social media, videos on YouTube and partnering with local universities in STEM events. A key to the success of these outreach efforts is the willingness of scientists and students to incorporate outreach efforts into their programs and to spend time formally and informally improving their communications skills for these efforts. Successful outreach strengthens the field by ensuring continued investment in research and by inspiring the next generation of scientists to enter the field.

NSCL/JINA Outreach

Zach Constan, Michigan State University

Public outreach is critical for increasing awareness/understanding of our work and reaching future scientists. The opportunity here is to make a personal connection between nuclear science and the community – demystifying the research and those who pursue it. The challenges are familiar: funding and volunteers. At NSCL and JINA, our priorities are to use funds to lower barriers (by traveling to potential audiences or offering free programs) and involve as many scientists as possible so they can form relationships with participants. Our organizations and DNP members must consider how to value outreach and express that value with money and systemic benefits for outreach participation (e.g. offering recognition in tenure review).

ARUNA Outreach

Umesh Garg, University of Notre Dame

ARUNA is a consortium of university-based low-energy accelerator laboratories performing nuclear physics research. Its current membership consists of accelerator laboratories at the Florida State University, Hope College, Ohio University, Texas A & M University, Union College, University of Kentucky, University of Notre Dame, University of Massachusetts at Lowell, University of Washington, and the Triangular University Nuclear Laboratory. It was stated in the report to NSAC by the Rare-Isotope Bean Task Force that "Low-energy University-based Facilities…constitute an extremely productive and cost effective component of the national program.…These facilities play an important role as focal points for attracting and educating the next generation of nuclear scientists."

ARUNA laboratories have also played an important role in public outreach for our field, with the credo that nuclear physicists have the best chance to explain "nuclear" and "radiation" to the public so that they can make rational decisions and not fear-based ones. Indeed, these laboratories are uniquely suited for the task because an on campus laboratory provides something for the Department and University to "show off", and is extremely useful in providing direct "hands on" experience even to young students. As such, ARUNA laboratories reach out to vast segments of society to educate and enthuse them about our science.

The extent of outreach activities at these laboratories is wide and varied: Open Houses, Laboratory tours, "Saturday Morning Physics", presentations and demonstrations in classrooms of local K-12 schools, Nuclear Science Merit Badges for Boy Scouts, participation in the "Science Day" programs at local schools, an Art to Science summer camp, Physics of Atomic Nuclei summer program, and courses on radiation and applications of nuclear physics. All these activities are being undertaken with practically no budgetary provisions and are possible solely because of the willingness of the faculty and graduate students at these laboratories to generously contribute their time and effort. However, without some budgetary support specifically for outreach activities, these efforts are in danger of being jeopardized.

The Contemporary Physics Education Project – To the future

Howard Matis, Lawrence Berkeley National Laboratory

The Contemporary Physics Education Project (CPEP) – http://CPEPphysics.org – produces current physics materials for high school students, college students and the general public. Our products are both scientifically accurate and visually attractive. As a result they are widely used in the high schools and colleges. They frequently used in movies and TV program. Our past work was done by ourselves in collaboration with students and with the help of visual artists. When we produced our previous work, building a web site was simple and we easily were able to produce widely used sites such as http://abc.lbl.gov. Now, work on the web is much more complicated. Viewers except to see high quality graphics. Furthermore, CPEP produced a book called "A Teacher's Guide to Nuclear Science" which has been put on the web at http://abc.lbl.gov/wallchart/guide.html. This site is outdated and should be modernized in both the physics content and the method of presentation.

Resources are needed to update the materials to modern standards. For instance, a very usual project would be to move the "Teacher's Guide" to a tablet app. To do this, we need skilled programmers and a graphic artist to update the figures. Nuclear physics experts can easily be found from our community. What is needed is a way to collaborate with student journalists and students interested in science outreach. There should be support to facilitate such collaborations. Just as our experiments use engineers, we need skilled people to facilitate our communication programs.

The Nuclear Science Division at Lawrence Berkeley National Laboratory participates in public outreach each year with its Nuclear Scouts Day for Boy and Girl Scouts – http://nuclearscienceday.lbl.gov. This event is completely oversubscribed and is limited only by the number of volunteers that we can get to staff the event. Each year we have to deny hundreds of students from our program because of this lack of resources. It is very desirable for this program to be publicized to other groups in the San Francisco Bay Area and throughout the nation. Other groups could use the expertise that our Division has gathered from this outreach effort and we could benefit from other groups experience. It would be be very desirable to have a formal way for outreach groups to share our experiences and a way to encourage other groups to participate in these very popular events.

Overview of applications for defense and security

Anna Hayes, Los Alamos National Laboratory

The application of nuclear physics both to societal issues and to other fields of science began at the turn of the 20^{th} century. As our understanding of the nucleus and its properties has advanced, the sophistication of the applications increased. Today, nuclear medicine plays a major role in diagnosing and treating disease, almost 15% of the world's electricity comes from nuclear energy, and nuclear proliferation represents one of the most serious threats facing our world. Here I overview some of the energy and defense related applications, with an emphasis on the transition of the field from its early days to its addressing the problems facing modern society.

High signal-to-background neutron detection using neutron to gamma converters

Marian Jandel, Los Alamos National Laboratory

Prior Results:

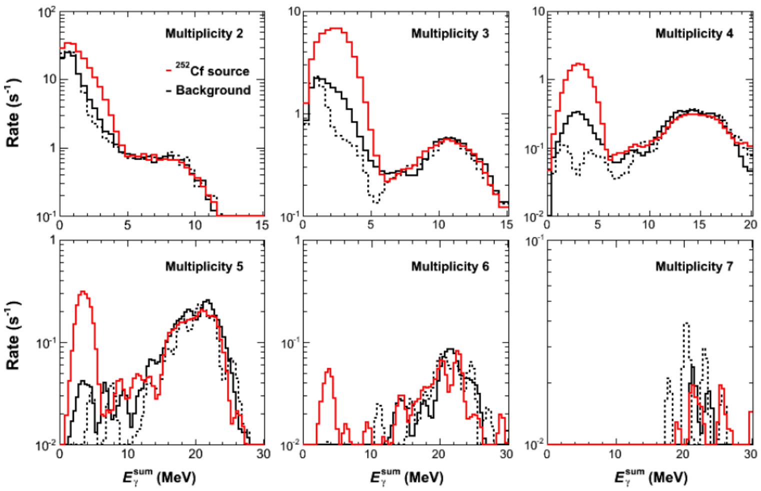
- Detector response was studied with PuBe and ^{252}Cf sources. Measured internal neutron detection efficiency of 15%
- Cascade transitions in ^{111}Cd and ^{113}Cd were measured in DANCE experiments.
- A statistical model of the cascades in ^{113}Cd was created and used in Geant4 simulations of the prototype

Prototype of the detector system, patent pending

Technical Challenges:

- Increasing the efficiency – large solid angle coverage, background reduction
- Short time measurements – using dedicated analog electronics or DSP (Digital Signal Processing chip) on board of the analog-to-digital cards
- High rate of the cosmic background – using a veto detector above the prototype
- Design a faster data acquisition
- Deconvolution of the ^{113}Cd measured spectra of capture γ rays for the use in the full scaled up model

Results:



^{252}Cf measurements with the prototype (red histograms) compared with background measurements with (black solid histograms) and without (black dashed histograms) cadmium sheets.

Planned Accomplishments:

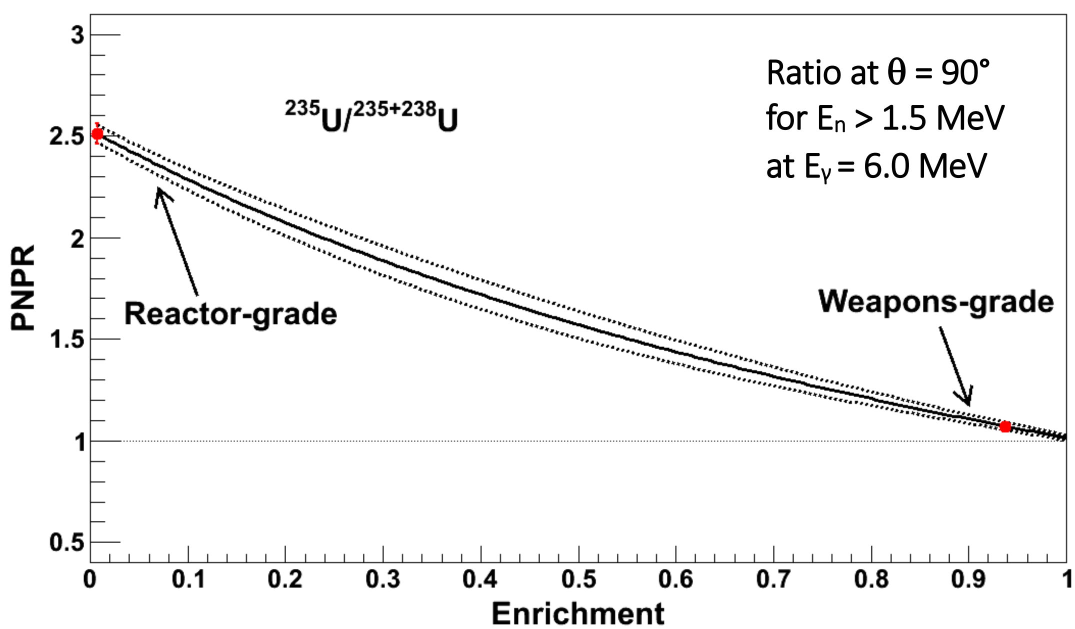
- Develop new methods of γ-ray spectra deconvolution using DANCE measurements
- Develop a Monte-Carlo capture gamma-ray event generator for future use in the Geant4 model of the full scale-up model
- Repeat the measurements with ^{252}Cf and further optimize the system exploring different detector orientations and separations
- Benchmark ^{252}Cf results with the Geant4 model
- Write a parallel code for the full scale model including optical photon transport (if needed)

UNCLASSIFIED, Office of Defense Nuclear Nonproliferation R&D, Nuclear Weapons and Material Security 2013, LA-UR-13-21775, Supporting Investigators: G. Rusev, T. N. Taddeucci

A novel method to assay special nuclear materials using polarized photofission

Henry R. Weller, TUNL and Duke University

The 100% linearly polarized γ-ray beam of the HIγS facility has been used in an experiment designed to measure the prompt neutron polarization ratios (PNPR) on a number of actinide samples, where the PNPR is the ratio of the neutrons detected parallel to those detected perpendicular to the plane of polarization of the beam. Running at beam energies below 7 MeV and using a neutron threshold of 1.5 MeV assured us of the fact that all detected neutrons resulted from photofission. It was discovered that the PNPR values were nearly equal to 1.0 for all odd-A targets, while they were significantly greater than 1.0 for even-A samples. This difference in the PNPR values can be exploited to measure the fissile versus non-fissile content of special nuclear materials, and potentially to detect the presence of fissile material during active interrogation. An example of the dependence of the value of the PNPR on the enrichment of a sample consisting of an admixture of ^{235}U and ^{238}U is shown in the Figure below. The red points are measured values, the solid black curve is the interpolation using the measured relative neutron yields, and the dotted lines indicate the systematic uncertainties.



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Application of nuclear physics of national security

Dennis McNabb, Lawrence Livermore National Laboratory

Nuclear science is an important component of our national ability to support stockpile with predictive simulation capabilities in the absence of testing and to strengthen the accountability of nuclear materials. Nuclear data and experimental techniques are fundamental to the experiments and first-principle physical models that are used in these endeavors. These areas of applied nuclear science make strong use of advances in our understanding of nuclear reactions, the coordinated development of nuclear data tables with a range of nuclear scientists across many different application spaces, and the use of science facilities (Accelerators and HPC) and new detector technologies to answer or address applied science questions.

Increasingly we need young scientists trained in nuclear physics to have a broader scientific perspective: to recognize, embrace and help tackle scientific challenges outside their main discipline as the most challenging problems being addressed by the National Laboratories are multi-disciplinary in nature. Another impediment to progress is the lack of applied accelerator and measurement facilities with easy access. This infrastructure was traditionally found at both US academic institutions and national laboratories, but has largely decayed away. The evolution of the nuclear threat over time has created the need for new set of nuclear science capabilities that cuts across the missions of many different government programs.

There is an opportunity to change the game in nuclear security by pursuing transformational R&D on nuclear material properties, detection, and use. But it will require a careful rethinking of the state-of-the-art capabilities needed to work with nuclear material, radioactive samples, and intense particle and photon sources that can establish new, transformational experimental capabilities to drive innovative R&D.

Cosmic ray radiography of the damaged cores at Fukushima

Chris Morris, Los Alamos National Laboratory

In an application of nuclear physics a facility for flash radiography has been developed at the Los Alamos Neutron Science Center (LANSCE), which uses Coulomb multiple scattering of the 800 MeV proton beam to radiograph a range of experiments. Transmitted protons are imaged through a collimator, which determines the contrast, using magnetic lens onto a scintillator. The scintillator is imaged by fast gated cameras to provide motion pictures of dynamic experiments at frame rates from hundredths of Hz to 10's of MHz. Protons have proven far superior to high energy x-rays for flash radiography. Although this facility is primarily used for studying very fast phenomena such as high explosive driven experiments for stockpile stewardship, it is finding increasing application to other fields, such as tomography of static objects, phase changes in materials and the dynamics of chemical reactions.

Multiple scattering radiography using cosmic rays, a spinoff of proton radiography, is being used for homeland security. In this case the trajectories of incoming and outgoing muons are measured in position sensitive detectors and the scattering angles are used to infer radiation length weighted path lengths. Information from the cosmic ray trajectories allows three dimensional images to be made of the volume encompassed by the detectors. This technique is very sensitive to high atomic number materials. Cosmic ray imaging has proven to be able to quickly identify significant quantities of shielded nuclear materials in cargo and vehicles. This technique is currently under study in a number of facilities around the world.

Finally, the great Tōhoku earthquake and tsunami off the pacific coast of Japan in March 2011 lead to a catastrophic loss of cooling of three reactors at Fukushima Daiichi. There is still considerable uncertainty about state of the melted cores. Modeling and experiments have shown it is possible to image the cores using cosmic ray detectors mounted outside of the reactor buildings. Detectors are currently being fabricated to use this technique to image the core of the reactor #2. This information we be used to help guide the future cleanup efforts.

Nuclear Data: Defense & Security

David Brown and Elizabeth McCutchan, Brookhaven National Laboratory

For the many federal agencies involved in homeland security, there are several areas in which nuclear science contribute. Projects in these areas typically encounter issues with nuclear data when detection schemes or event scenarios are modeled using simulation codes such as MCNP or GEANT. These simulations are used to lay the groundwork for proposing and planning new projects and also to optimize the design or to analyze the performance of nuclear systems rather than performing experiments involving SNM which require extensive authorization and are costly. The simulation capabilities are built upon high-quality fundamental nuclear cross section and decay databases, such as the ENDF and ENSDF nuclear data libraries. These evaluated databases incorporate the detailed information available from experiments and from nuclear models, and allow simulations to model the underlying physical phenomena accurately.

A 2005 study, still very relevant today [1], lists many of the areas in which nuclear science has an impact including detection of radiological and nuclear materials being transported into or through the US and monitoring, detection, and analysis of nuclear explosions and nuclear weapons proliferation through radionuclide monitoring and other detection capabilities. These projects revolve around different detection strategies which may be grouped by interrogation style (active vs. passive), signal (correlated or not, prompt or β-delayed) and material of interest (major or minor actinides, fission products, structural materials or light nuclei such as C, N, O and H). In addition to the β-delayed data needs ref. [1] highlighted the need for photonuclear/photofission and activation cross section data.

More recently the possibility to use antineutrinos ($\bar{\nu}_e$) for nonproliferation monitoring has been studied. Nuclear reactors provide the highest intensity source of "man-made" antineutrinos, which are emitted in the β decay of all the neutron-rich fission products. The need to precisely understand the $\bar{\nu}_e$ spectra emitted from the products of fissioning systems is underscored by the first measurements of θ_{13} from the Daya Bay [2], RENO [3], and Double Chooz [4] experiments, the suggestion that there may be a reactor antineutrino anomaly caused by sterile neutrinos [5], and the potential use of antineutrino monitoring for nuclear safeguards [6].

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Accelerator applications in the environment

Ed Hartouni, Lawrence Livermore National Laboratory

Accelerator Mass Spectroscopy is used to measure the chronology of lake sediments. The lakes provide an important, widely distributed set of "recorders" of regional climate and can provide, in principle, a high resolution and high precision record of paleoclimatology. This has been achieved using the recent advances in ^{14}C AMS together with stable isotope measurements.

A second recent application has been the proposal to develop accelerator pollutant scrubbing. While the application of high-flux accelerators as a radiation source to drive radiolysis in waste streams has been known for decades, recent interest in applying it to scrub pollutants in exhaust stacks has been kindled by the review of the accelerator R&D program within the DOE. This application makes use of a number of nuclear science competencies including accelerator science and the interaction of radiation with matter.

Nuclear Data: Energy & Climate

David Brown and Elizabeth McCutchan, Brookhaven National Laboratory

The β-decay properties of fission products have an impact on a variety of applications of nuclear science involving fission such as nuclear energy production, nuclear safeguards, and stockpile stewardship. Although hundreds of radioactive isotopes are produced in fission, often detailed nuclear data on the β-decay properties of only a handful of key isotopes is needed. With high-quality fission-product beams now available at many radioactive beam facilities around the world, detailed studies of β decay can be performed to improve the nuclear data.

The neutrons emitted following the β decay of fission products (known as delayed neutrons because they are emitted after fission on a timescale of the β-decay half-lives) play a crucial role in reactor performance and control. Reviews of delayed-neutron properties [1-4] highlight the need to obtain high-quality data for a wide variety of delayed-neutron emitters to better understand the time-dependence and energy spectrum of the neutrons as these properties are essential for a detailed understanding of reactor kinetics needed for reactor safety and to understand the behavior of these reactors under various accident and component-failure scenarios. With improved nuclear data, the delayed-neutrons flux and energy spectrum could be calculated from the contributions from individual isotopes and therefore could be accurately modeled for any fuel-cycle concept, actinide mix, or irradiation history. High-quality β-delayed neutron measurements are also critical to constrain modern nuclear-structure calculations and empirical models that predict the decay properties for nuclei for which no data exists and improve the accuracy and flexibility of the existing empirical descriptions of delayed neutrons. However, spectroscopy of 0.1- to 10-MeV neutrons is challenging and the quality of the data available today for individual nuclei is limited – in some cases discrepancies as large as factors of 2-4 in recent measurements of β-delayed neutron branching ratios have been uncovered and for the vast majority of neutron emitters, the energy spectrum has not been measured. Due to the challenges and limitations associated with existing techniques, a new approach to performing β-delayed neutron spectroscopy would be valuable for collecting the high-quality, reliable data needed for applications.

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Uncertainty quantification in fission cross section and fragment distribution measurements at LANSCE

Fredrik Tovesson, Los Alamos National Laboratory

Some nuclear physics quantities are of great importance to applications, but the absolute uncertainties of the measurements required for the applications are smaller than have been achieved. For example, for many current fission cross-sections uncertainties remain on the order of 3% or more. Nuclear physicists working in both applications and basic research have devised detector solutions drawing on their experience in basic science to propose and execute precision measurements. In this case, a small TPC is used to mitigate the systematic uncertainties of existing techniques to push the absolute uncertainties below the 1% level required for the application.

Nuclear data needs for decay heat applications

Filip Kondev, Argonne National Laboratory

Reliable quantification of the decay heat induced by nuclear fission is a critical factor in the design of nuclear facilities for electricity generation and for the post-irradiation handling of nuclear fuels (fuel discharge, storage, transport and reprocessing, and waste handling). The total decay heat, as a function of cooling time, impacts both the safe operation and various legislative and economic aspects of nuclear power generation. New reactor design studies have highlighted the need for high quality decay data, and careful propagation of uncertainties associated with these measurements. The reactor fuels under consideration demand a broader range of decay data than was previously required. These new reactor studies require decay data for neutron-rich nuclides (primarily fission products and actinides) which include determinations of half-lives, isomers, mean beta and gamma-ray energies, feeding intensities, delayed neutrons, and careful estimates of all their uncertainties.

In nuclear energy applications, the evaluation of the decay heat have been usually performed using the summation (microscopic) method, where one follows the decay and a buildup of about thousand fission products (FP) from the known fission yield and decay data. In this approach the decay heat (including both the beta- and gamma-ray components) is calculated from the known FP decay schemes as the total sum of the energy releases from all individual β^--decaying $x - x$ nuclides existing at a relevant cooling time. Although extensive measurement efforts have been developed over the past fifty years in response to the increasing need of the applied nuclear reactor community for accurate decay data, differences still exist between the decay heat standards and experiments, as well as between different decay data libraries. The experimental data are particularly scarce for short cooling times (less than 3000 s) where the decay of neutron-rich FP dominates owing to the large β^--decay Q values (~4-10 MeV) and the fact that β^--decay feeding intensities into the high-energy region of the daughter nuclei are frequently missing ("pandemonium effect"). This is the case for almost half of all known FP involved in the fission process (~1200 nuclides). These missing intensities account for about 20-40 % loss in energy releases. In order to compensate for such a loss, due to paucity of experimental data, a gross beta-decay modeling is frequently used in the decay data libraries, and therefore these libraries become "contaminated" by theoretical predictions rather than been on a firm experimental footing. Attempts made in past to resolve data deficiencies using high-resolution γ-ray spectroscopy techniques (HRGS) were only partly successful, due to the low efficiency and sensitivity of the detector systems used in these measurements and the lack of pure, and intense sources. The Total Absorption Gamma-ray Spectrometry (TAGS) method, which is in principle free from the "pandemonium" problem, has been applied in the past only to about 50 cases, albeit this technique is compromised when isomers are presented or β-decay delayed neutrons are emitted. The urgent need for improved decay data on neutron-rich FP for Advanced Fuel Cycles applications has been also outlined at IAEA, where request for new measurements have been made for a number of high-priority nuclides.

Nuclear power industry needs

Ward Rigot, D.C. Cook Power Plant, AEP

The Nuclear Power industry is experiencing its first real growth in 35 years. Back in 1977, nuclear power accounted for ~20% of US power generation, but there were no new plants built between 1977 and 2014. During this time, total US energy production doubled, but the nuclear power industry capacity factor also doubled to ~89%, so that nuclear power still produces 19.6% of US total! Clearly this trend cannot continue, and recently four new units have been ordered and approved for construction. They are expected online by 2020. The industry is likely to experience significant growth and there are some critical workforce issues.

Based on informal discussions with other Chemistry managers in the nuclear power plants, there is a serious shortage of trained radiochemists as a top priority. However, in terms of nuclear physics training, with the advances in digital pulse processing hardware, larger detectors and more sophisticated software, we as an industry, rely heavily on the vendors to set up systems to make them useful without needing in-depth knowledge. There are some training courses available, either through vendors or companies like NWT; but it still takes 1-2 years of development to get an individual to be proficient. There need to be more students trained in fundamental nuclear physics at a time where there are fewer students than ever. Additionally, knowledge of the nuclear fuel cycle and especially fission yields to assist is understanding basic mechanisms for fuel failures is still needed.

From a nuclear engineering standpoint, there continues to be a need for engineers with a solid understanding of reactivity and fuel depletion through a 18-24 month fuel cycle at nuclear power plants. There is a need for understanding corrosion chemistry at normal operating pressures and temperatures at nuclear power plants as well. This includes metallurgy and protective passivation layers on in-service piping and components. There is training provided by agencies such as EPRI for this.

Plant physiology studies using radioisotope tracing

C.R. Howell, Duke University and TUNL

Data on atmospheric CO_2 concentration determined using Antarctic ice core samples show that the current concentration of atmospheric CO_2 is at its highest level over the last half million years [Pet99]. The debate within the scientific community on whether the changes in the levels of green-house gases in the atmosphere due to human activities is impacting the planet's climate is largely settled. The leading conclusion of a recent review by the National Research Council [NRC10] is that "Climate change is occurring, is caused largely by human activities, and poses significant risks for a broad range of human and natural systems".

The responses of plants to changes in environmental conditions are not sufficiently well understood to enable reliable predictions of the consequences of climate change on plant life. A multidisciplinary collaboration that include nuclear physicists at TUNL, biologists at Duke University and the particle detector group at JLab is conducting research with the aim of providing new insights on the physiological responses of plants to external stimuli, in particular, to differences in environmental conditions. The collaboration is using radioisotope labeling to investigate the dynamical responses of plants to changes in environmental conditions, e.g., concentration of atmospheric CO_2, nutrient availability, light intensity and temperature. The approach is to identify cause-effect relationships between changes in environmental conditions and responses that are manifested as shifts in the allocation of substances by the plant. The measurement method is based on tagging sugars and minerals with short-lived radioisotopes that can be imaged using positron emission tomography (PET) or beta particle detection. The radioisotopes are produced in the tandem laboratory at TUNL and the labeling measurements are carried out at the Phytotron, an environmentally controlled facility for plant research at Duke University. A PET image sequence taken on a corn plant is shown in Figure 1. These frames illustrate the capabilities of this technique to determine the relative sugar allocations throughout the plant and substance transport quantities, e.g., speed.

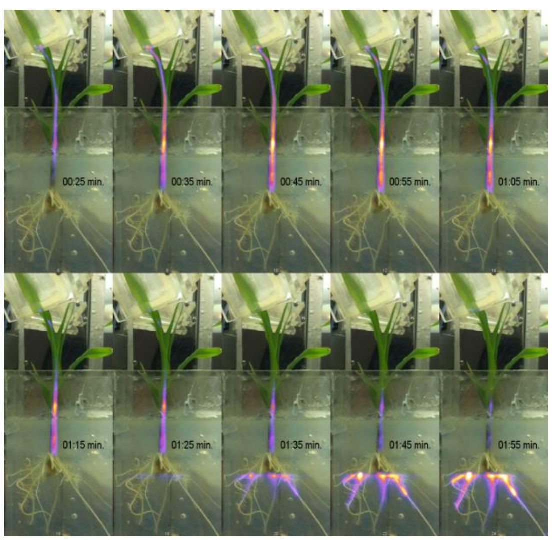

Fig. 1. Positron emission images of a corn plant taken at different times after exposing the uptake leaf (top left corner of each image) to a pulse of air tagged with $^{11}CO_2$. The images are co-registered with photographs of the plant. The color enhancements indicate the measured amount of ^{11}C-tagged sugars in the various parts of the plant. Each frame is reconstructed using data collected over a counting time of 10 minutes. The beginning time of each frame is written on the image.

(from S. Lee et al., "Imaging corn plants with PhytoPET, a modular PET system for plant biology," in 2013 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), 2013, pp. 1–3.)

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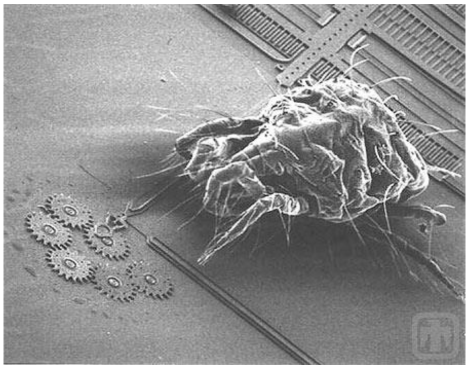
Nuclear batteries

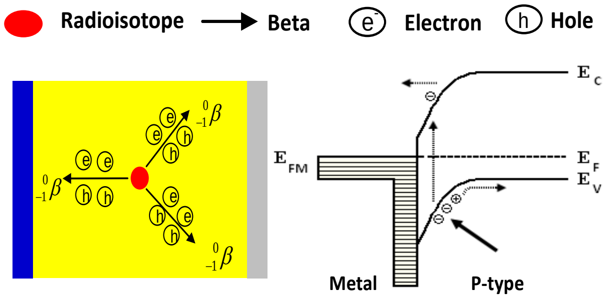
David Robertson, University of Missouri

Micro electro mechanical systems (MEMS) are the microscopic structures integrated onto silicon that combine mechanical, optical and fluidic elements with electronics. Micro electro mechanical systems have been developed for use as thermal, magnetic and optical sensors and actuators; as micro chemical analysis systems; as wireless communication systems; and as biomedical devices. These systems, which have the ability to gather and process information, compute a course of action, and control the environment or a macro system, will be the product differentiator of the 21st century, pacing the level both of defense and commercial competitiveness. The ability to employ these systems as portable, stand-alone devices in both normal and extreme environments depends, however, upon the development of power sources that can provide milliwatts of power for a machine that is smaller than a dust mite.

Miniaturized nuclear batteries are an ideal solution to the power challenge as the energy density (J/kg) of radioactive material is approximately one million times greater than that of lithium ion batteries. Moreover, in contrast to chemical based power sources and photovoltaics, nuclear batteries can operate for extended periods of time and in extreme environments. Recent technology advances are allowing us to produce miniature nuclear batteries that convert the energy of alpha particles and beta particles emitted in radioactive decay into useable electrical power at the MEMS scale.



Example of MEMS gears. Photo from www.mems.sandia.gov.



Betavoltaic schematic

Particle therapy technology: Where are we now? Where do we need to go?

Jay Flanz, Harvard Medical School, Massachusetts General Hospital

The goal of radiotherapy is to reduce the dose to healthy organs while targeting the disease. This requires knowing where the disease target is and delivering a beam to that target. For practical implementations, technology costs and costs to a patient, including quality of life have to be considered. Particle therapy has developed from the 1960's when particle therapy was delivered in a physics lab environment to the 3rd generation facilities which include the beginning of more compact facilities, beam scanning technology and more integrated imaging. However, there is still much to be gained by minimizing the discrepancy between the technology and the physics potential of the particle beam, at an affordable cost.

The technologies for most parts of a proton therapy system, including accelerator, beamline, gantry, beam delivery and patient set-up equipment are fairly well advanced, with the exception of the Gantry structure size, instrumentation for beam delivery and more integrated, on-line, imaging capability.

The degree of beam delivery conformity has been enhanced with beam scanning but we are still living with instrumentation technology from 50 years ago, with 100's of microseconds of time latency. One of the key aspects of a 'time-dependent' beam delivery like scanning, is the recognition that the target/patient move. One serious limitation of the ability to deliver a beam more rapidly, is the instrumentation and controls that are used. Otherwise, motion mitigation methods are needed, which sometimes even increase the time for treatments, further aggravating the effects of motion. A faster beam delivery would also require improved control of the beam position and the charge delivered at any given location. Aspects of the beam timing from the accelerator, beamline and instrumentation are often ignored and attempts to build different accelerators seem to be given more press, while the true limitations of beam delivery are not yet optimized.

In addition, there is the recognition that adaptive radiotherapy is the key towards further improvements in dose conformity. This could include tumor shrinkage over days, to motion management during the delivery of a fraction. Improved and on-line imaging is necessary for this, both to determine where the target is, and where the beam is going. While Cone Beam CT is now being integrated into particle therapy treatment rooms, and while PET has been included, there is only slow development on particle imaging techniques like proton radiography, prompt gamma and in-room PET, but without significant support from particle physics instrumentation experts. This is partly due to the fact that particle therapy vendors do not have this expertise and they are the primary 'developers' of integrating technology. When government facilities do actually contribute to the field, these days, they are patenting implementations and utilizing hard legal methods to protect the work from being utilized for the greater distribution.

Capital costs for particle therapy have been reduced somewhat, and there are no shortage of accelerator options. Gantry geometries have been revisited a few times, however the goal of physically installing a particle therapy system in the same space as a photon treatment system has yet to be realized, although the MeVIon systems at various hospitals and the ProTom system to be integrated at MGH are steps towards this. More importantly, this effort seems to have taken precedent over the improvement of the beam delivery accuracy and speed which could be resolved by improved instrumentation and control systems.

There are a number of technical challenges to address the key themes in particle therapy. It is hoped that the government supported particle and nuclear physics community could apply the appropriate science and technology that would help achieve the realization of these themes.

Past and future innovations in proton therapy

Niek Schreuder, Provision Center for Proton Therapy

The first hospital based proton therapy system, installed at the Loma Linda University, started operations in 1990 and by the end of 2015 only 15 proton therapy centers will be treating patients in the USA. The majority of these are freestanding outpatient radiation therapy centers. This relatively slow rate of adoption of proton therapy resulted in a significant delay in the implementation of very important technologies, mainly volumetric imaging, in proton therapy. Most of the missing technologies are state of the art in photon therapy facilities and are used routinely. Today the focus in proton therapy is on compact facilities that will allow for easier and faster installation at a reduced cost. Leveraging superconducting technologies allows for even more compact accelerators and rotating gantry systems. Pencil beam scanning beam delivery techniques are now widely used and are available in most of the newer proton facilities and allows for a higher efficiencies in treatment preparation and delivery. The majority of Proton therapy vendors now provide pencil beam scanning only solutions for their latest systems. The top priorities that future systems are and should be addressing are mainly linked to operational efficiencies to reduce recurring costs, reduced footprint to allow for easier replacement of photon therapy systems, implementing volumetric imaging solutions, reducing the proton range uncertainties and improved system reliabilities and the maintainability of such systems. Revised training programs and methodologies will also help to improve the utilization of future proton therapy systems.

Innovation in radioisotope production: A university perspective

Amanda M. Johnsen, Pennsylvania State University

There has been a long-standing history of production of some radioisotopes in nuclear medicine treatments and diagnostics (e.g. ^{99m}Tc) and there has been ongoing medical research for novel treatments and diagnostics involving several other radioisotopes (e.g. ^{67}Cu, ^{223}Ra). From a university perspective there are recent developments that will alter the production of medical isotopes in the future. First, the federal radioisotope programs have been restructured within the DOE. Also, there has been a recognition that there are serious educational needs in workforce development for new radioisotope production. Both of these factors influence the university-based efforts to produce radioisotopes. There exist current challenges to develop new ways to make standard "in-demand" isotopes as well to improve separation procedures, where university researchers can play a significant role. One example is the ^{64}Cu and ^{67}Cu pair of isotopes that can be used as a new area of "theranostic" isotope pairs, one for therapy and one for imaging (diagnostic). New production techniques and increased medical research and development is needed here. Still other production methods and cost-effective separations for promising □-emitters are also needed.

Nuclear physics and innovation in medical imaging

Gordon D. Cates, University of Virginia

There are multiple paths leading from nuclear physics to innovations in medical imaging. In some cases, the connection are quite direct. The subject matter of nuclear physics research, often in collaboration with MDs, leads directly to medical technology. In other cases the connections are more indirect. For example, technology is developed for a nuclear physics experiment that later turns out to be useful. Finally, it is often the case that people trained in nuclear physics have the right skill sets to go on to work in the medical-device industry. Most medical-device companies that develop new technology employ physicists, and often they are nuclear physicists.

A wonderful historical example of the direct connection between nuclear physics and medical imaging is the development of Positron Emission Tomography (PET). The positron, the antiparticle of the electron, was discovered in cosmic rays by Carl Anderson in 1932, a discovery for which he won the Nobel Prize in 1936. The discovery of the emission of positrons by radioactive isotopes, by Frédéric and Irène Joliot-Curie, followed in 1934. The use of annihilation radiation from positrons for medical imaging purposes followed 16 years later, in 1950, and is generally credited to Gordon L. Brownell, who held a Ph.D. in physics from MIT, and William Sweet, an MD and at that time chief of neurosurgery at Mass General. It is interesting to note that the title of Brownells Ph.D. thesis was "Physical Properties and Measurement of Beta-Rays". Despite early successes using positron annihilation radiation to better visualize brain tumors, many people were skeptical that this technique would become widespread. Among the obstacles were the fact that positron emission generally comes from isotopes that are made using instruments such as cyclotrons. In recent years, however, the commercial availability of compact cyclotrons has caused the use of PET to become widespread, defying many initial expectations.

Nuclear imaging, of which PET is but one example, plays a critical role in diagnostic medicine. A common radioactive tracer is the isotope technitium-99m, or ^{99m}Tc. Like certain other tracers, ^{99m}Tc can be attached to various molecules that are preferentially absorbed by tumors. It is thus possible to inject a patient with ^{99m}Tc, and using what is called a "gamma camera", visualize tumors in the body that would be quite difficult to visualize otherwise. The research that pushes this type of imaging forward has everything to do with the interactions between radiation and matter, and is typically performed by people trained in nuclear physics. So not only was nuclear physics responsible for the fundamental science that led to nuclear imaging, it is also the field that supplies the necessary manpower.

Nuclear physics experiments, like other types of fundamental research, often rely on the invention of exotic technology that later proves useful for various applications. An example of this is the development of large "polarized gaseous targets" of ^{3}He, an isotope of helium. While developed initially to better understand the structure of the neutron, it was soon demonstrated by some of the same nuclear physicists that developed the targets that ^{3}He, when inhaled, could be imaged using MRI, providing images of the gas space of the lungs of unprecedented resolution. This type of "lung imaging" has become quite important in both the study of pulmonary disease, as well as the development of drugs for the treatment of pulmonary disease.

In short, whether it is the discovery of important new science, the development of new technology to perform experiments, or the training of people who go on to work in industry, nuclear physics plays a critical role in medical imaging.

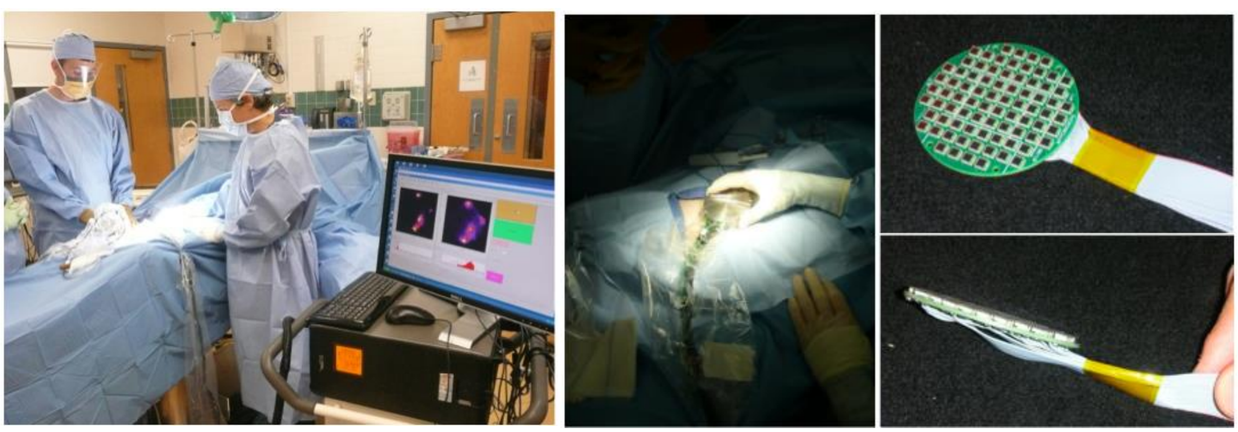
Nuclear physics detector development: A Source of advances in nuclear medicine imaging

Drew Weisenberger, Jefferson Lab

The detector systems and technologies developed for particle physics experiments are a source of innovation which when refined further have applications in nuclear medicine. Nuclear medicine uses radioisotopes as tags for biologically active molecules. Radioisotopes that emit high energy photons and beta particles are incorporated into particular molecules that have a biological function of interest to researchers or clinicians. The tagged molecules are injected or introduced in vivo into biological systems such as animals used as models for human disease or into humans for diagnostics or treatment.

The bio-distribution of radioisotope tagged molecules is imaged externally by detector technology that has origins in basic nuclear physics research. The medical imaging modalities of Single Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET) and X-ray Computed Tomography (X-ray CT) have benefited from advances in detector technology for nuclear physics detectors. Scintillators, photomultiplier tubes, silicon photomultipliers (SiPM) and avalanche photodiodes are examples of nuclear physics detector technologies with applications in biomedicine. As these technologies are advanced for nuclear physics research they often can bring new capabilities to nuclear medicine such as higher spatial resolution, higher sensitivity, organ specific and compact uses such as a hand-held gamma camera for surgery. These new technologies have the potential of economically improving America's healthcare.

Nuclear physics research approached in an interdisciplinary manner can play the role of providing cutting edge nuclear physics detector technology to nuclear medicine. A well supported nuclear physics technology transfer culture provides opportunities and a catalyst for new technology development. Applications of nuclear physics technology that lead to commercial enterprise and further technology refinement can also provide new tools for basic research.



Hand-held silicon photomultiplier based gamma camera used to identify radioisotope labeled sentinel lymph nodes with cancer involvement during breast cancer surgery.

Nuclear Data: Health & Medicine

David Brown and Elizabeth McCutchan, Brookhaven National Laboratory

There Molecular imaging and therapeutic probe development are fast growing technologies which rely on a stable supply of radioisotopes. Research into non-traditional radionuclides can develop innovative designs to investigate specific biological activity and processes.

Precise knowledge of the radiation emitted by medical isotopes is needed to determine the total dose received by the patient, the specific dose to targeted tissue, the cost of infrastructure in production facilities (i.e. shielding requirements) and the background in imaging technologies. A beta-decay level scheme is usually determined by measuring the gamma-ray transitions which are emitted from the daughter nucleus, then balancing the gamma-ray intensity at each excited level to determine the beta-decay feeding to each level. If the detection system is not sensitive to weak gamma rays, not only will the total gamma-ray radiation be underestimated, but also the deduced beta feedings will not be properly determined. Many important medical isotopes were last studied decades ago with low-sensitivity detection systems.

As an example, the 2008 NSAC report on Isotope Production [1] identified 9 high-priority isotopes for biology, medicine, and pharmaceuticals, over half of which the decay was last studied over 30 years ago. Gamma-ray spectroscopy was in its infancy when such measurements were performed. Since then, the field has made tremendous advances, with current systems making use of >100 HPGe detectors. This naturally provides significant gains in overall efficiency, but also in coincident efficiency (determining when gamma-rays come in cascade). In addition, the now common practice of incorporating Compton-suppression into these arrays drastically reduces the overall background. Shortcomings in the beta-decay databases, as they relate to medical isotopes, can easily be remedied through definitive and accurate assessments of the radiation emitted by important radionuclides using state-of-the-art gamma-ray arrays currently available at a number of facilities.

Cross sections for production of radioisotopes with proton beams have focused on the energy region of 100 MeV and below. Above 100 MeV, the cross sections for protons on various targets are virtually unexplored. This leads to tremendous discovery potential using proton beams from two of DOE's major isotope production facilities (BLIP with up to 200 MeV protons and IPF with up to 800 MeV protons). The cross section as a function of excitation energy of the projectile is generally determined through the so-called activation technique where a target foil is irradiated for a fixed time and then moved to a low-background counting area where the subsequent decays of the radioactive products are assessed using gamma-ray spectroscopy. Such measurements require very simple experimental setups which could lead to high-impact results via the identification of new production routes for radioisotopes.

Such measurements can strongly benefit from a solid set of theoretical calculations. While the main reaction library (ENDF/B-VII.1) provides a complete reaction picture over a full energy range for neutron induced reactions, a similar, complete library is missing for proton-induced reactions. Such information would be essential for scoping out whether a particular production route is worth investigating experimentally. A code such as BNL's EMPIRE would be capable of generating a proton-induced reaction library for proton energies up to several hundred MeV's to complement the experimental investigations.

[1] NSAC Isotopes Subcommittee, "Isotopes for the Nation's Future: A Long Range Plan" (2008)

Isotope harvesting at FRIB

Graham Peaslee, Hope College

There are several radioisotopes that are useful for practical applications that cannot be made readily from conventional sources. A working group has compiled a list of relatively long-lived "orphan" isotopes that currently are not easily obtained, and these radioisotopes include: ^{32}Si, ^{44}Ti, ^{44,47}Sc, ^{48,49}V, ^{67}Cu, ^{77,85}Kr, ^{88}Zr as well as many rare earth and actinide isotopes. One alternate method of radioisotope production includes the myriad of spallation target reactions that will occur when the Facility for Rare Isotope Beams (FRIB) is operational. The standard mode of operation at FRIB will be to produce a rare isotope beam for a primary user, for example ^{58}Ca from a ^{82}Se beam. At the same time, the fragmentation of this production beam will produce as many as 1000 other isotopes, some of which might be collected (harvested) and used for other experiments or applications if the proper equipment is installed in the separator and suitable physical/chemical separation techniques are developed.

The potential applications of these harvested isotopes range from the determination of neutron cross sections for homeland security to kinetic studies of radionuclide uptake in biological processes. An example of harvesting the medically interesting ^{67}Cu will be presented, with early results from an aqueous target installed at the National Superconducting Cyclotron Lab, and the subsequent radiochemical separations developed at Washington University and Hope College. There is a recognized need for further investment in specialized equipment at FRIB as well as a critical need in workforce development to fully realize the potential of this alternate source of radioisotopes.

LANL's isotope production facility

Eva Birnbaum, LANL Isotope Program

LANL's Isotope Production Facility (IPF) is an intermediate target area at the Los Alamos Neutron Science Center (LANSCE), which is configured to maximize production of high purity and high specific-activity isotopes. With a high current (230 μA) beam of 100 MeV protons incident on a water-cooled stack of three targets, the IPF can be tuned to maximally produce specific long-lived isotopes in the solid targets (currently primarily ^{82}Sr and ^{68}Ge). Of course, plenty of unique research and development questions remain to be explored: What other isotopes might be produced in these energy slots? Can we take advantage of secondary neutron flux? IPF can also be tuned for a 40 MeV incident proton beam, which allows other high-specific isotopes to be produced.

LANL has a nearby dedicated Hot Cell Facility for radiochemical processing and distribution of purified isotopes. LANL currently coordinates through the Office of Science, Nuclear Physics and the DOE National Isotopes Development Center. There are clearly future workforce needs, especially for: Nuclear physicists to model different nuclear reactions and to perform cross section measurements; Engineers to design optimum targets with consideration for temperature flux and materials compatibility; radiochemists to design and improve chemical separations from the targets; and hot cell operators. We need to ensure continued strong ties to the isotope community, including providing opportunities for student/postdoc training in the field, as well as expanded opportunities for university collaborations with national labs.

Nuclear science applications important for national security

Mark Stoyer, Lawrence Livermore National Laboratory

The Stockpile Stewardship Program (SSP) is responsible for ensuring the safety and reliability of the nation's nuclear weapons without resorting to testing. This requires improving the quality and availability of nuclear data used for interpretation of nuclear events. This is accomplished with a combination of robust experimental efforts at current and future facilities, such as FRIB, and theory. Isotopes of interest span a range of half-lives which means a combination of experimental techniques will be required to make new measurements. Nuclear data improvements needed include better measurements of half-lives, decay branching ratios, reaction cross-sections, level density and gamma-ray strength functions. Two examples illustrate some of the needs: 1) any measurements on reaction cross-sections induced on short-lived fission products which require in-beam experiments, and 2) measurements on reaction cross-sections of radioactive nuclei for which isotope harvesting is beneficial.

Improved knowledge of production and destruction reactions for A=95 fission products is desired. The cross-sections of interest within the region are shown in Fig. 1, with ^{95}Sr being perhaps the most important nuclide to obtain experimentally determined cross-sections. Generation of ^{95}Sr beams at CARIBU or FRIB, coupled with developments of inverse kinematics reactions such as (d,p) reactions, will enable experimental determination of a few key cross-sections and improve the theoretical models used to calculate the other reactions and cross-sections. Experimental data for several other mass regions, A=144 and A=147, is desired.

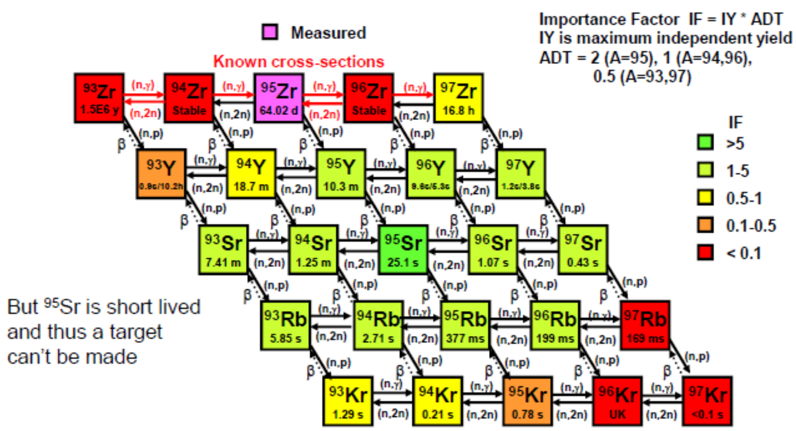


Fig.1: Part of the chart of nuclides showing the neutron rich fission products of interest to the SSP.

Isotopes such as ^{48}V and ^{88}Zr are suitable for isotope harvesting and construction of targets for conventional neutron induced experiments. In many such cases, experimental cross-section information is completely lacking, as is shown in Fig. 2 for ^{88}Zr(n,γ)^{89}Zr. This effort is synergistic with the medical community's development of ^{89}Zr as a medical imaging diagnostic isotope. Isotope harvesting schemes to obtain ^{67}Cu from the FRIB beam dump water have shown significant promise—additional chemistry to purify Zr isotopes is under development.

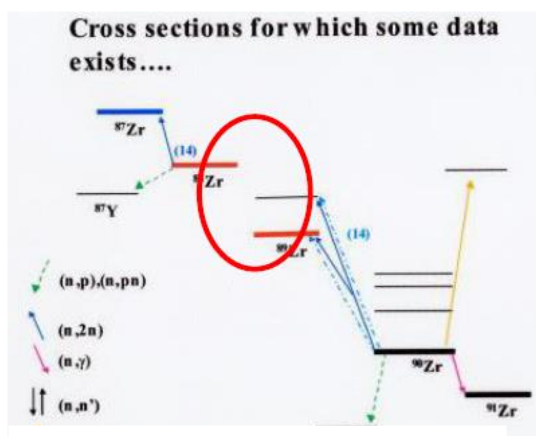


Fig. 2: Cross-section set for Zr showing reactions for which some experimental information is known—many other reactions are needed.

LLNL-ABS- 659983

Trends and applications for MeV electrostatic ion beam accelerators

Mike Mores, National Electrostatics Corporation

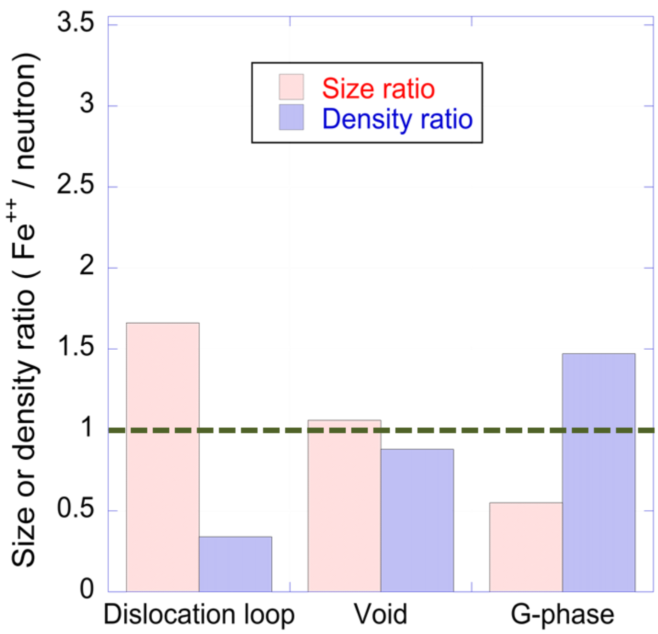
A brief history of the ion beam accelerator industry shows that it really began to expand in the 1980's with the materials analysis market accessible with ion beams. This includes all the standard techniques such as RBS, ERD, NRA, channeling, PIXE, μRBS, μPIXE, which were accompanied by such technological advances as computer control, true unattended operations, improved detector hardware and analysis software. This led to impressive applications in art forgery detection (RBS/PIXE) at the Louvre, biomedical studies into aluminum in Alzheimers, and atherosclerosis (PIXE), rapid aerosol measurements (PIXE), Er light amplifiers and high Tc superconductor studies, among many others. Then in the 1990's Accelerator Mass Spectrometry altered the market permanently with its ability to measure radioisotope ratios very precisely. This led to headlines in archeology (Dead Sea scrolls, Shroud of Turin, Ice man, Kennewick man), climate studies (aquifers, ocean carbon dioxide reservoirs), biomedicine (pharmacokinetics, biodistribution, drug delivery), and forensics (dental and hair records, Pu in Marshall Islanders), just to name a few. The third major category for application of these accelerators has been in ion beam implantation and materials modification.

Currently, National Electrostatics is experiencing a significant increase in ion beam accelerator orders. Between 2010 and 2014, NEC has sold 18 complete AMS systems and 17 complete ion beam analysis/ion implantation/other accelerator systems, in addition to 16 partial systems and refurbishments. There are 10 AMS systems and 8 IBA/other systems currently in manufacture as well as 13 upgrade or component orders. This crush of orders has pushed back delivery dates to early 2017 at the moment! There is significant interest in recent advances in compound-specific AMS, high-resolution RBS, high-current electron accelerators, multiple-beam damage studies, and high-charge-state positive ions. Over 80% of the newest AMS systems are going towards biomedical applications because of its unparalleled sensitivity.

Ion beam applications at the Michigan Ion Beam Laboratory (MIBL)

Elizabeth Getto, University of Michigan

Determining the material response under reactor irradiation is key for the design and implementation of current and advanced nuclear energy systems. Ion beams have been shown to be an effective surrogate in emulation of in-reactor radiations. Ion beams provide well controlled, accelerated and low cost alternatives to traditional reactor testing. In addition, well designed ion beam experiments have been combined with other characteristics of the extreme reactor environment of high temperature, stress and corrosion. The Michigan Ion Beam Laboratory is a state of the art facility at the University of Michigan, which is well-equipped to meet challenges in radiation materials testing. Capabilities include single ion irradiations using a by 3 MV Pelletron accelerator, a 1.7 MV Tandem accelerator as well as a 400 kV ion implanter. These accelerators can provide ions for both materials damage study as well as ion beam analysis including Rutherford backscatter spectroscopy, nuclear reaction analysis, elastic recoil detection and ion channeling experiments. Dual and triple beam capabilities are expected within the next year. Success at this facility is dependent on continued funding of both the facilities and training of the highly skilled personnel required to operate such a facility.



Comparison of size and density of dislocation loops, voids and G-phase precipitates by Fe^{++} irradiation to a dose of 188 dpa at a dose rate of ~10^{-3} dpa/s, and with neutrons in FFTF to a dose of 155 dpa at 440°C and a dose rate of ~10^{-6} dpa/s.

G.S. Was, Z. Jiao, E. Getto, K. Sun, A. M. Monterrosa, S. A. Maloy, O. Anderoglu, B.H. Sencer, M. Hackett, Scr. Mater. ***88*** *(2014) 33.*

Ion beam analysis of consumer products

Graham Peaslee, Hope College

This innovation is at the interface between applied nuclear science research, education and workforce development and science policy. A low-energy particle accelerator at Hope College is used to perform Ion Beam Analysis to measure the surfaces of materials via tradition methods such as Particle Induced X-ray emission (PIXE) spectroscopy, Particle Induced Gamma-ray Emission (PIGE), Rutherford BackScattering (RBS) analysis, Nuclear Reaction Analysis (NRA), and others. It serves as an excellent interdisciplinary training ground for future nuclear scientists learning traditional nuclear physics techniques (particle acceleration, high vacuum systems, detector systems, data acquisition systems, data analysis…) at the interface with atomic physics, surface science, materials, geochemistry, biochemistry, etc.

Two recent studies have expanded our repertoire of studies into the area of consumer product testing: testing for the presence of halogenated flame retardants in polyurethane foam and plastics, and screening for the presence of perfluorinated chemicals in textiles, food-packaging papers, carpets and cosmetics. All of these chemicals are known to be persistent in the environment, bioaccumulative and toxic, which lead to fundamental scientific questions about their prevalence in consumer products as well as their fate and transport through the environment and the correlation with human health. The traditional analytical methods for detection of these chemicals involves significant wet chemistry and is both time-consuming and expensive to perform. Ion Beam Analysis provides an alternative quantitative method for detection and characterization of the halogens in these molecules and can serve well as a rapid non-destructive screening test for their presence in a wide range of consumer products.

This mixture of fundamental research, applied nuclear physics and science and policy implications attracts student interest, provides an excellent educational opportunity for future workforce development and has the potential to make a significant societal impact through the application of accelerator-based physics.

APPENDIX D: EXAMPLES OF OUTREACH ACTIVITIES

PubSci: Big Bang Physics

BROOKHAVEN NATIONAL LABORATORY

Organization: Brookhaven National Laboratory, Stakeholder Relations
Contact: Tara Shiels, tshiels@bnl.gov,
Chelsea Whyte, cwhyte@bnl.gov
Audience: General Public
Funding source: DOE Office of Science, Brookhaven Science Associates

A trio of physicists affiliated with the Relativistic Heavy Ion Collider (RHIC) and two Brookhaven Lab science writers kicked off a new science café series on March 11, 2014. The event, dubbed “PubSci” for its location in a local pub, drew more than 70 community members who were eager to ask questions and engage in conversation about "Big Bang Physics and the Building Blocks of Matter.” With the science writers serving as talk show style hosts, panelists Berndt Mueller, Brookhaven’s associate laboratory director for Nuclear & Particle Physics, Paul Sorensen of RHIC’s STAR collaboration, and Ágnes Mócsy, a theoretical physicist at RHIC and an associate professor at Pratt Institute, presented brief overviews, humorous anecdotes, and a spirit that invited audience participation.

“It’s a cool thing that you brought this amazing science out of the borders of the Lab to us,” said one attendee. “It was great to hear the scientists talk about themselves and joke around and just be casual. I also really liked hearing about the future of the research at RHIC.”

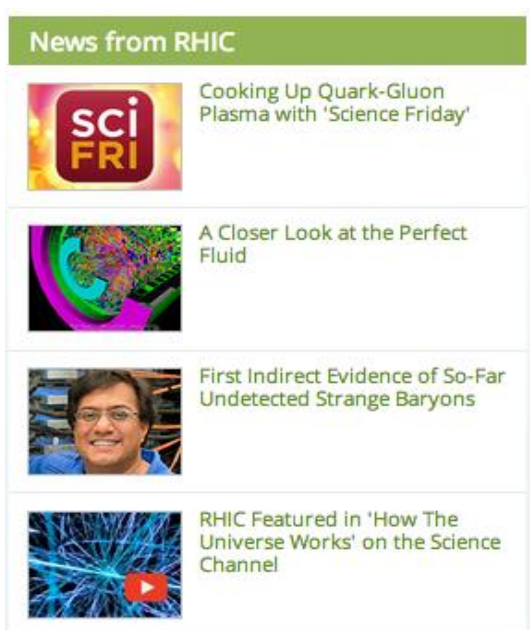
The scientists were equally enthusiastic. “It was an awesome experience to engage with so many interested people in such a public, yet intimate setting,” Mueller said. “The many questions we received really helped us convey the excitement of the science.”

website: http://www.bnl.gov/newsroom/news.php?a=24704

RHIC Features and Press Outreach

Organization:	Brookhaven National Laboratory, Media & Communications Office
Contact:	Karen McNulty Walsh, kmcnulty@bnl.gov
Audience:	General Public
Funding source:	DOE Office of Science

Brookhaven Lab regularly features engaging stories about the research at the Relativistic Heavy Ion Collider (RHIC) on its public-facing web pages, distributes these stories to the mainstream media, and points to them via social media (Twitter, Facebook, and Tumblr) to encourage wider distribution and independent coverage of our nuclear physics research. Examples include stories at the start and end of the most recent experimental run, features on the careers of physicists trained at RHIC, and updates on scientific findings such as the search for strange baryons and the source of gluon spin. We also routinely attend scientific meetings and science communication events where we pitch coverage of RHIC physics to reporters.



Examples of the payoff from these efforts include: a "How to Make Quark Soup" video featured on NPR's *Science Friday* broadcast and website, a segment in the *Discovery Science* series "How the Universe Works," a column on the "awe-inspiring" research at RHIC in *The Wall Street Journal*, prominent coverage in a popular book, *Heat: Adventures in the World's Fiery Places*, stories appearing on a variety of news sites and blogs, and high-tech elements of RHIC experiments featured in ads for the New York State Empire Development Corporation and Apple Computers.

website: www.bnl.gov/rhic/news2/

RHIC Summer Sunday/Tours

BROOKHAVEN NATIONAL LABORATORY

Organization: Brookhaven National Laboratory, Stakeholder Relations
Contact: Tara Shiels, tshiels@bnl.gov
Audience: General Public
Funding source: DOE Office of Science, Brookhaven Science Associates

This year, nearly 100 scientists and engineers working on research at the Relativistic Heavy Ion Collider (RHIC) volunteered their time to explain nuclear physics research and give tours to visitors. Highlights include:

RHIC Summer Sunday: Atom-Smashing Fun
Held one Sunday every summer as part of Brookhaven's series of open-house events, and advertised via local print and radio media, this year's RHIC Summer Sunday on August 3 attracted approximately 1,300 guests of all ages. Visitors took part in interactive demonstrations and toured the RHIC accelerator tunnel and the STAR and PHENIX detectors to learn about the exploration of nuclear matter from the scientists conducting the research. Other attractions included hands-on activities and a "Phenomenal Physics" show in Berkner Hall.

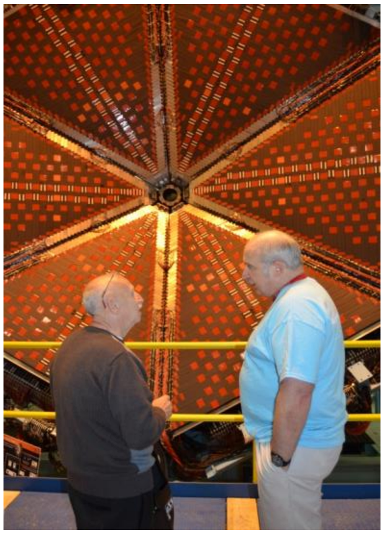
Other FY14 RHIC Tours
This year, an estimated 1,550 guests visited one or more RHIC facilities—including the Main Control Room, RHIC accelerator tunnel, STAR, and PHENIX—as part of tours arranged by the Lab's Stakeholder Relations office. Visitors included local and international high school, college, and university students (e.g., Fujishima High School, Charterhouse School UK, Suffolk Community College, NYIT, Ohio State University, U.S. Merchant Marine Academy), elected officials, community and business organizations (e.g., Women's Club of Riverhead), and conference participants (e.g., Undergraduate Women in Physics). As one attendee said, "It was inspiring to see such advanced technology. I am now interested in applying to an internship or research project at BNL."

websites: http://www.bnl.gov/stakeholder/summersundays.php
http://www.bnl.gov/stakeholder/tours.php

Jefferson Lab Open House

Organization: Jefferson Lab
Contact: Kandice Carter
Audience: General Public
Funding source: Jefferson Lab, DOE

Jefferson Lab holds a biennial open house, allowing the public to tour many of its facilities and interact with scientists. During the 2014 Open House: Accelerating Discovery, more than 5,500 visitors toured the ~200 acre site. All four of the lab's experimental halls were open for the first time, and more than 2,200 visitors toured the lab’s accelerator. The event also featured R&D centers, local university physics departments, booths from local science centers, cryogenics shows and science lectures.



website: https://www.jlab.org/openhouse

NSCL Exhibits at Science Festivals

Organization: Michigan State University
Contact: NSCL Outreach, visits@nscl.msu.edu, 517-908-7363
Audience: General public
Funding source: MSU/NSF

Teams of volunteers from NSCL have hosted booths at numerous Science Festivals. Through hands-on demonstrations and one-on-one time with visitors, NSCL faculty/students/staff communicate their passion for research to a large audience in a short time.

Recent events include large venues such as the MSU Science Festival and MidWest Space Fest as well as smaller audiences at the local elementary school's "Science Night." At the USA Science and Engineering Festival in Washington, D.C., over 5000 people visited our booth in three days.

website: http://sciencefestival.msu.edu/

NSCL Open House

MICHIGAN STATE UNIVERSITY

Organization: Michigan State University
Contact: NSCL Outreach, visits@nscl.msu.edu, 517-908-7363
Audience: General public
Funding source: MSU/NSF

NSCL open houses offer the community a chance to see what nuclear science is and how our work helps solve some of the greatest mysteries in the universe.

Example activities:

- Tour the lab to see superconducting cyclotrons, experimental detectors, and plans for the next-generation heavy ion accelerator.
- Educational movies and science rap videos in "NSCL Theatre".
- Talk with nuclear scientists and graduate students about their work on the frontiers of rare-isotope research.
- Get a personal demonstration of superconductivity, radioactivity, cosmic rays and more in the Expo Area.

website: http://www.nscl.msu.edu

NSCL Public Talks

Organization: Michigan State University
Contact: NSCL Outreach, visits@nscl.msu.edu, 517-908-7363
Audience: General public
Funding source: MSU/NSF

Groups that are too large for NSCL tours or can't travel to the lab are offered talks about nuclear science or, for school groups that request it, careers in research (and STEM) fields. NSCL faculty, staff and students often travel around Michigan to tell their story to these audiences. Such talks have been attended by over 2400 guests in 2014.

One talk organizer said: "Your presentation was outstanding and the highlight of the day. Literally every conversation I had the rest of the day included very positive comments about your presentation!"

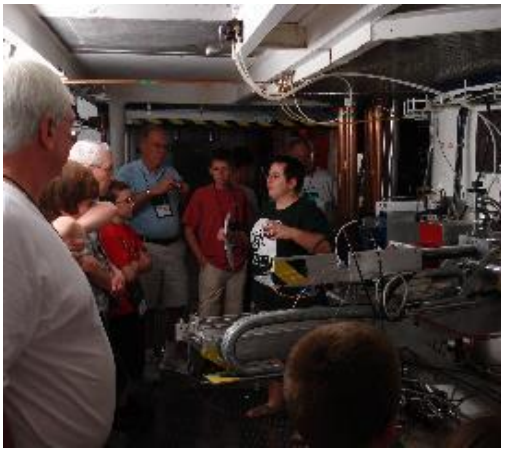
website: http://www.nscl.msu.edu

NSCL Laboratory Tours

Organization: Michigan State University
Contact: NSCL Outreach, visits@nscl.msu.edu, 517-908-7363
Audience: General public
Funding source: MSU/NSF

NSCL offers 90-minute tours "behind the scenes" to groups of 10-50 visitors. Guests include school classes, community organizations, MSU students and alumni, etc. Over 3500 people tour the lab every year. The average tour includes a demonstration-heavy 40-minute introduction to the lab before splitting into small groups for a walk through the experimental areas.

Visitors express great satisfaction with their tour experience, rating it an average a 4.87 out of 5. A sample reaction: "The entire program is a credit to Michigan State University."

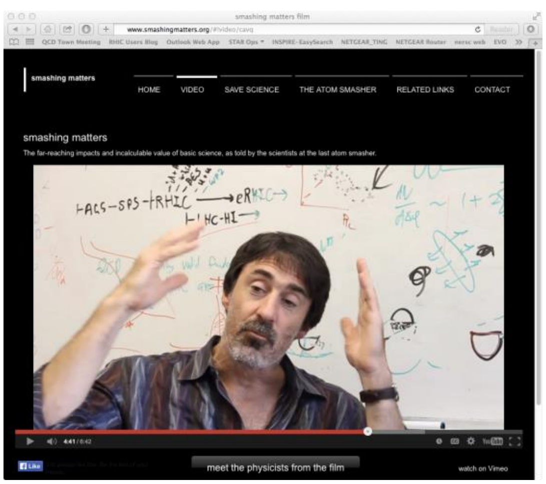


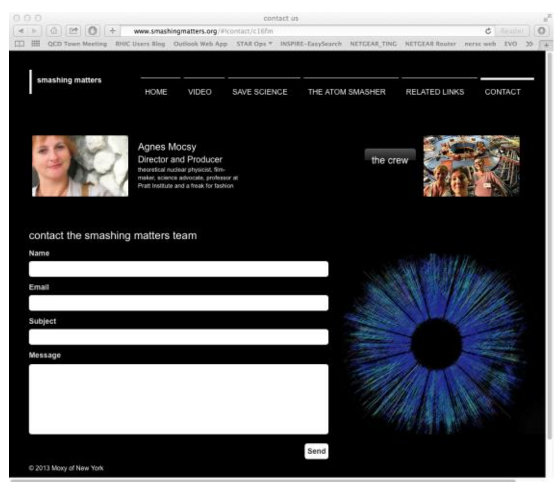
website: http://www.nscl.msu.edu/public/tour

"Smashing Matters"
Op-Doc and Webpage

Organization: Pratt Institute
Contact: Ágnes Mócsy, (917) 209-1516, amocsy@pratt.edu
Audience: General Public
Funding source: Pratt Institute, Brookhaven Science Associates, Duke University

"Smashing Matters" is an inspirational and informative Op-Doc released in 2013 explaining the importance of fundamental research through interviews and illustrations. The highly polished film was produced in collaboration with film and writing students from Pratt Institute. An accompanying web-page offers more detail on how to support basic research. After viewing this video, representatives from Discovery contacted Prof. Mike Lisa (one of 10 scientists featured in the film) to appear in the show "How the Universe Works" on the Science Channel.

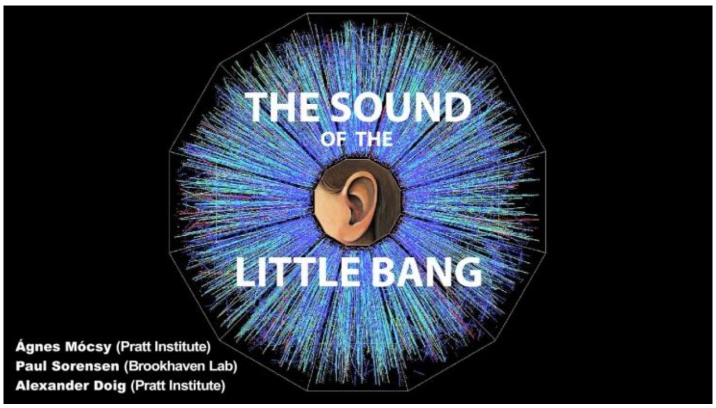


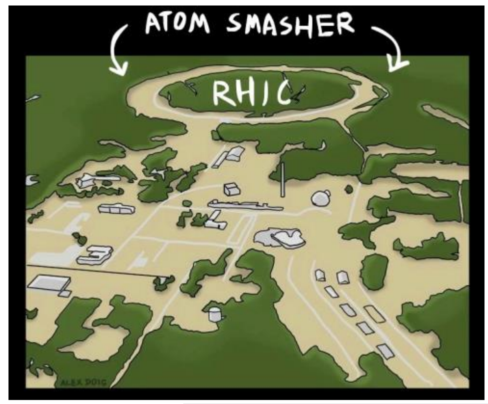


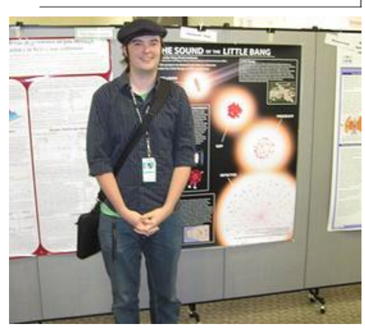
website: http://www.smashingmatters.org

“The Sound of the Little Bangs” Animated Video

Organization: Pratt Institute
Contact: Ágnes Mócsy, (917) 209-1516, amocsy@pratt.edu
Audience: General Public
Funding source: Unfunded







“The Sound of the Little Bang” is a groundbreaking animated video produced in a collaboration between BNL and Pratt Institute. The video provides an accessible explanation of a research break-through. The illustrations and animations were created by Alexander Doig, an undergraduate illustration major at Pratt. Alex presented his work at a RHIC/AGS Users Meeting. It was also presented in a talk at an APS meeting where it was selected as one of the highlights of the meeting. The project was written about by dozens of international news organizations and the videos have been viewed by approximately 40 thousand viewers from around the world. The impact of the video has been profound within the nuclear science community as well with verbiage from the narration now regularly echoed in scientific talks. This illustrates how collaborations between diverse fields can be mutually beneficial.

website: http://soundofthelittlebang.com/media.html

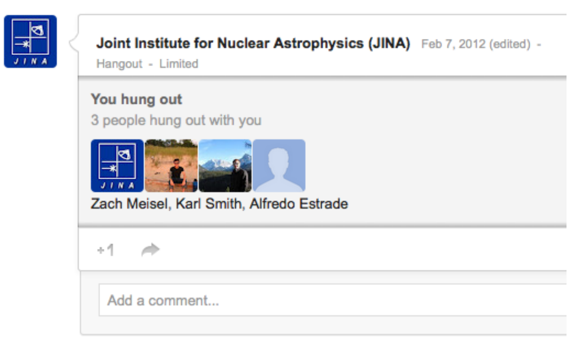
Web Activities

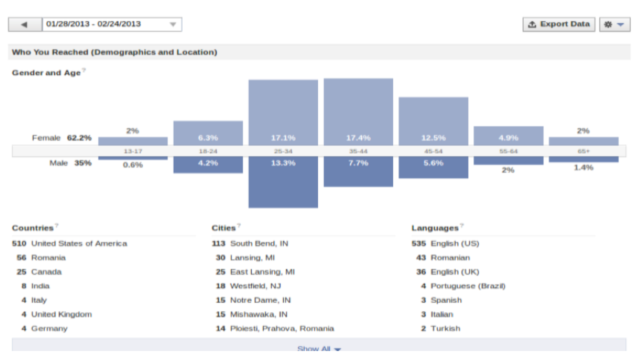
Organization:	University of Notre Dame / Michigan State University
Contact:	JINA Outreach, (574) 631-5326, jinaout@nd.edu
Audience:	General Public
Funding source:	NSF

The JINA Educational Gallery offers something for everyone, from movies, coloring sheets, and a slide show based on Harry Potter character names, to teaching materials and advanced course-based lectures. The gallery pages continue to receive 1000+ unique visits each year.

JINA is active in social media on its Facebook, Twitter, Google+, and YouTube pages. The most popular Facebook post to date, about International Women's Day, was seen by over 900 people. Most of the FB fans are women, ages 35-44 who live in or near South Bend. These are most likely mothers of students who have attended a JINA outreach program. We use FB to notify them of other local outreach events throughout the year. Almost 20% of the fans live outside of the United States.

JINA has posted 13 videos on YouTube, which have been viewed 1000+ times. These videos are a combination of educational content and videos about outreach events. The most popular video was a 'fun' experimental parody of the 12 days of Christmas, which was a joint project between scientists at MSU and ND. While growth on Twitter and Google+ have been slower than FB and YouTube, scientists and committees often use Google+ hangouts as a new way to video conference.





website: http://www.jinaweb.org/html/jinaprograms.html

Science Festivals

Organization: University of Notre Dame / Michigan State University
Contact: JINA Outreach, (574) 631-5326, jinaout@nd.edu
Audience: General Public
Funding source: NSF

Celebrate Science Indiana – Indianapolis, IN
JINA scientist participate in the annual statewide science expo in Indiana. JINA partners with a variety of Notre Dame departments and organizations each year. Over 5000 visit the festival and the Notre Dame booths regularly have 600+ visitors.

Science Alive – South Bend, IN
JINA staff and students participate in the annual St. Joseph County Public Library's Science Alive. 3,000 people regularly attended the expo, which features over 40 exhibits. Prior to the expo, JINA, ND Department of Physics and ND College of Science sponsor an exhibitor reception to provide an opportunity for exhibitors to network for new collaborations. The JINA room includes marshmallows in vacuum, LN2 demonstrations, radiation detectors, and a light absorption activity with gummy bears. It is often the most attended room by the public (700+) and press, earning JINA a front-page picture in the printed Sunday paper .

MSU Sci-Fest
MSU held their 2nd Science festival over the course of 9 days. One day was reserved for school groups to attend an expo of activities. Scientists from NSCL and JINA partnered for an extended exhibit which takes participants through the entire nuclear experimentation process from fragmentation and separation to detection. It also served as a test run for the USA festival below.

USA Science and Engineering Festival
JINA joined NSCL for the 3rd USA Festival this year. Scientists from NSCL and JINA partnered for an extended exhibit which takes participants through the entire nuclear experimentation process from fragmentation and separation to detection. We estimate 5000 participants took part in our activities.

Website: http://www.jinaweb.org/outreach/outreach_calendar.html

Neutrino Day

Sanford Underground
Research Facility

Organization: Sanford Underground Research Facility
Contact: Peggy Norris, pnorris@sanfordlab.org, (605)-722-5049
Audience: General Public
Funding source: Sanford Lab and local businesses and foundations

Neutrino Day is an annual science festival held in the Lead, SD community the second Saturday of July that has grown to attract more than 1000 participants. In 2013, the festival outgrew the surface facility at the Sanford Underground Research Facility and expanded downtown.

The whole community is now involved. At the Sanford Lab site, visitors can tour the Hoist Room, visit displays or ask questions of scientists working at the 4850L of the underground lab via high-definition videoconference. Down the hill in town, science lectures and hands-on activities for kids of all ages take place at the Historic Homestake Opera House, the Library, the Lead-Deadwood Middle School, the Homestake Open Cut and the Black Hills Mining Museum. Buses take participants between locations. Partners include the Lead Chamber of Commerce, the Lead-Deadwood Arts Council, South Dakota Public Broadcasting, Black Hills Power and many community volunteers.

website: www.sanfordlab.org

Street Physics at Texas A&M

Organization: Texas A&M University
Contact: S. Yennello
Audience: General Public
Funding source: NSF & TAMU

The TAMU Cyclotron Institute REU students put together a set of hands on activities and take them to the street – literally - each summer. Our local community hosts a First Friday event once a month where many members of the community fill the streets of downtown to enjoy art, music, and in July - science. It is always incredibly well received by all. The REU students enjoy engaging people of all ages in the fun and often once discussions started they end up explaining their research projects to the public. Numerous people have asked if we would be back other months. The event has been reported in the local paper. One professor in Engineering so liked the idea she approached me about "institutionalizing" it so we would have different groups of science and engineering students bring science to the streets throughout the year.

July is the perfect month for the NSF REU students as they will have gotten comfortable with being at TAMU and with each other and yet it is not so late in the summer that the students feel the tension of too many competing time commitments. Overall, this has been a very successful REU outreach event and we anticipate a similar outreach event will take place each year.


Sunday, July 15, 2012 Our Neighbors

The beauty of science

Eagle photo by Stuart Villanueva

Rudy Gonzalez of El Paso pulls a flower from a cup of liquid nitrogen during a physics demonstration at Downtown Bryan's First Friday. Gonzalez and his fellow students are part of the Research Experiences for Undergraduate Students program held at Texas A&M in conjuction with The Texas A&M Cyclotron Institute and the National Science Foundation.

website: http://cyclotron.tamu.edu/smp

Science Happy Hour

Organization: Yale University
Contact: John Harris, john.harris@yale.edu
Audience: General Public
Funding source: Yale Physics Department

To quote the news article about the event – "What happens when four physicists walk into a bar?" There are "an infinity" of possible answers to this question. One of them took place in New Haven just off the Yale campus – a "Science Happy Hour" where after a few introductions many questions about science were asked and answered, breeding discussions for the rest of the evening. Before the start of the event, slides were projected on a large screen depicting a Hubble Deep Field Telescope view of space, an artist depiction of the first instants of the Big Bang, an infamous strikingly-visual heavy-ion event, an awe-inspiring view of a behemoth LHC detector, and famous art depicting extra dimensions and distortions of space-time.

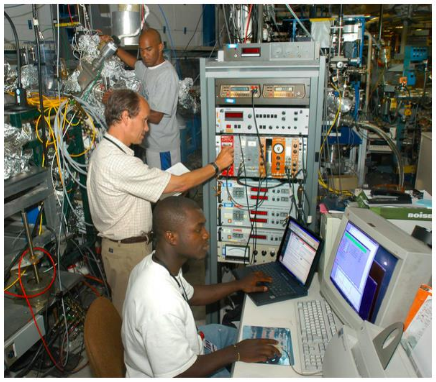
In the course of an hour and a half with a public moderator, the four physicists representing ALICE-USA, STAR, US-ATLAS and Nuclear Theory engaged the audience in a vivid discussion of physics topics ranging from the Big Bang to a Quark Gluon Plasma to the Higgs particle. Both the relevance of these in our understanding of nature and how people actually carry out this research were of interest to the crowd. Below are photos of the panel and half the room-full of the inquisitive audience that numbered around 70 at any one time. See the website below for more details about the event and panelists.

website: http://star.physics.yale.edu/BAREVENT/

Science outreach at BNL & RHIC

Organization: Brookhaven National Laboratory
Contact: Ken White
Grade Level: 1-12
Funding source: various

A key part of the mission of BNL's Office of Educational Program's mission is to encourage and promote science literacy. This includes participation in a number of DOE funded programs, such as SULI. FaST, CCI, ACTS and PST.



BNL also hosts the BSA funded Science Learning Center, serving 40000 students a year with information on RHIC, NSLS and NSRL.

In a partnership with the NYS Boards of Cooperative Education Services, Exploration Laboratories organize field trips to BNL, with lab activities developed in coorperation with BNL scientists, post-docs and grad students.

In depth high school student experiences are offered by the Minority High School Science Apprenticeship, Community Summer Science and High School Research Program programs

website: http://www.bnl.gov/education/

Jefferson Lab Physics Fest

Organization: Jefferson Lab
Contact: Jan Tyler
Grade Level: K-12
Funding source: Jefferson Lab

Jefferson Lab's Physics Fest is a two-hour field trip highlighting nuclear physics, demonstrations with cryogenics and plasmas, and career opportunities in the STEM fields. Nearly 6,000 students attended the events at Jefferson Lab in FY2014.

website: http://education.jlab.org/physicsfest/index.html

Saturday Morning Physics at Texas A&M

Organization:	Texas A&M University
Contact:	R. Rapp
Grade Level:	K-12
Funding source:	NSF & TAMU

- Introduced + directed at TAMU in 2006 by R. Rapp [part of NSF Career Award], joined by R.J. Fries in 2010 [NSF Career] (adopted from Fermilab version)
- **Entice high-school students about forefront physics research**
- 7 events each spring since '06
- Faculty lecture + discussion - break - quiz/demos/specials
- Well connected: Cyclotron / Physics&Astronomy / College of Science, high-school teachers (give students credit for attendance certificates)
- Involves grad students + postdocs, facebook
- Steady attendance growth, throughout Southeast TX (up to Dallas, Houston, San Antonio)

Year	2006	2009	2013
Average	16	100	145
Total	44	190	~250
Certificates	15	95	~130

website: http://cyclotron.tamu.edu/smp

Generation of Electrical Energy by Nuclear Fission and Other Phenomena

Organization: University of Dallas
Contact: Prof. Sally Hicks, hicks@udallas.edu
Grade Level: 3-5
Funding source: DOE-NEUP

A nuclear physicist from the University of Dallas has participated in STEAM Career Day at Stipes Elementary in Irving, TX. The focus of her presentations in 2013 and 2014 was nuclear energy generation in fission reactors and general energy production. Four classes of 3rd graders (2013) and 5th graders (2014) were introduced to hand-held generators and what happens in a fission reactor to generate electricity. They also viewed a little quantum physics by viewing spectral tubes through diffractive glasses. Additionally, time was spend encouraging students to take as much mathematics and science as possible at the different levels of their education. Stipes Elementary has a largely Hispanic student body.

5th graders at Stipes Elementary observe neon spectral lines during STEAM Career Day.

Art 2 Science

Organization: University of Notre Dame / Michigan State University
Contact: JINA Outreach, (574) 631-5326, jinaout@nd.edu
Grade Level: 2-12
Funding source: NSF

Art 2 Science Camp is a summer science program for students between the ages 8 and 17 years old, where students over 14 serve as junior counselors. The camp is an extension of our after-school program of the same name which introduces children to the wonders of the physical universe. This camp utilizes a multidisciplinary approach to learning, incorporating reading, writing, music, art and science. Participants learn about physics, astronomy, and other sciences through reading books, creating art, dancing, and hands-on activities.

The camp is continually evolving from both the administration side and the educational content. We have added a number of community partners since the camp's debut in 2011 including a variety of centers and departments at ND, Snite Museum, DPAC, and St. Joseph County Parks. In 2013 and 2014 the Director of Outreach and Education for the NASA Planck Mission joined us to teach physics through dance. Based on this success, we're decoupling a Science 2 Theater camp for older students next year.

We also extended the camp to Lansing for 2014 through a partnership with Union Missionary Baptist Church and Next Young Phenom, Inc.

website: http://www.jinaweb.org/outreach/artCamp/

Classroom Support

Organization: University of Notre Dame / Michigan State University
Contact: JINA Outreach, (574) 631-5326, jinaout@nd.edu
Grade Level: K-12
Funding source: NSF

Classroom Support Materials (Formerly Mini-Grants) (K-12) are geared toward curriculum enhancement, providing science teachers with the opportunity to acquire supplementary teaching materials appropriate to nuclear astrophysics. Teachers apply for support online, indicating their list of materials and identifying how they relate to nuclear astrophysics, and how these materials are intended to impact their instruction. JINA purchases the approved materials and has them shipped directly to the school. Often support is related to instructional materials that are introduced in PAN or other JINA outreach programs, enabling teachers to effectively apply their experiences with JINA in their classrooms. During the past year, there has been a sharp increase in educator interest regarding the marble nuclei materials. Some have been introduced through science expos or PAN, but many have learned of the lessons and activities through 2nd or 3rd hand-knowledge after teachers take the materials to their own local science fairs and expos.

website: http://www.jinaweb.org/html/jinaprograms.html

Nuclear Pipeline

Organization: University of Notre Dame / Michigan State University
Contact: JINA Outreach, (574) 631-5326, jinaout@nd.edu
Grade Level: 2-12
Funding source: NSF

The variety of programs targeted at different ages of youth has developed into a **"JINA Pipeline"** for students to progress through different levels as they gain experience. After recognizing this, we are actively trying to cultivate the pipeline and keep in touch with participants in between programs when possible. Many of our student participants stay involved with JINA through more than one program. The programs for middle school students have been "feeding" the programs for high school students for the past few years. For example, 2 of the 2012 PAN students had previously taken the course on nuclear astrophysics through the MST program at MSU. Many students who attend one PAN program apply to attend another at a different location. Previous PAN teachers recommend interested students to PAN. We recruit local PAN graduates to participate in outreach efforts, including mentoring younger students. The new initiatives for elementary students are also beginning to "feed" the middle school programs.

Current example: At PAN @ ND 2014, the male dorm counselor participated in JINA's Sensing Our World (now organized by another entity), PIXE-PAN, PAN@MSU, and helped with a variety of outreach prior to this summer. He will also be an adult counselor at this summer's Art 2 Science Camp. One of our campers attended PAN@MSU last year and another attending PAN@IMSA earlier this year. A 3rd, local student, was a Junior Counselor at Art 2 Science Camp last year.

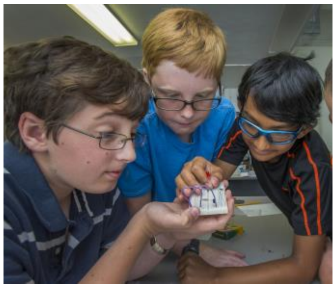
website: http://www.jinaweb.org/html/jinaprograms.html

Smashing and Detecting Particles

Organization:	Brookhaven Laboratory, Office of Educational Programs
Contact:	Bernadette Uzzi, buzzi@bnl.gov
Grade Level:	Middle/high school
Funding source:	DOE Office of Science, Brookhaven Science Associates, NSF

Brookhaven Lab's science educators run a series of programs at the Lab and in local schools to introduce middle/high school students to techno-logies and principles essential to explorations in nuclear physics. This year, 104 students participated in a one-hour program to learn about particle detection by assembling cloud chambers and analyzing trails left by cosmic rays. Another 84 took part in experiments to assemble a model linear accelerator analogous to one at the Relativistic Heavy Ion Collider (RHIC). Students experimented with the arrangement of magnets to propel steel marbles down a straight track and launch them into a fixed target and head-on collisions. They also learned about accelerator applications from exploring the nature of matter to developing cancer therapies.

The Lab also hosts students for weeklong summer courses. 37 high school students attended this year to learn about RHIC and other experiments that seek to understand matter at the dawn of time and the origin of mass, as well as dark matter, dark energy, neutrinos, and the matter/antimatter asymmetry in the universe. The course for middle school students—focused on the science behind cutting-edge breakthroughs in engineering—served 34 students. Through structural design, circuit construction, and experiments with electromagnetism, students learned how scientists and engineers work together to design and build charged coupled devices, particle detectors, and linear accelerators. Summer program students also toured RHIC facilities. As one student said, "It was valuable seeing the actual locations where the work is done."



websites: http://www.bnl.gov/stakeholder/summersundays.php
http://www.bnl.gov/stakeholder/tours.php

Future Physicists of Florida

Organization: Florida State University
Contact: Paul Cottle, pcottle@fsu.edu
Grade Level: Middle, High School
Funding source: Florida State University

Moving the needle on the number and diversity of engineers and physical scientists educated in the US will require us to capture students – particularly girls and members of minority groups – before they leave the science and engineering pipeline in high school. Future Physicists of Florida is an honor society that inducts students who show mathematical promise in middle school, usually in an Algebra 1 class. In the fall of 2014, students from five middle schools in four cities (Jacksonville, Orlando, Pensacola and Tallahassee) were inducted in ceremonies at FSU and the University of West Florida. Faculty members follow up with visits to participating schools in the spring to encourage students to pursue the challenging high school math and science programs necessary to properly prepare for college majors in engineering and the physical sciences.

website: http://futurephysicistsflorida.wordpress.com/

BEAMS

Organization:	Jefferson Lab
Contact:	Jan Tyler
Grade Level:	5th, 6th, 8th Students
Funding source:	Jefferson Lab

The BEAMS — Becoming Enthusiastic About Math and Science — program is a partnership involving Jefferson Lab and Newport News City Public Schools that supports inner-city students as they progress from the 5th to the 6th and 8th grades. These students and their teachers visit Jefferson Lab for periods of two to four days for science and math activities conducted by scientists, engineers and technicians. The goals are to increase the representation of minorities and women in the science and engineering workforce, to motivate and strengthen students' academic preparation, and to provide teachers with classroom activities based on science and technology. In FY 2014, the BEAMS program involved 1,275 students.

website: http://education.jlab.org/indexpages/teachers.html

Nuclear Science Day for Girl Scouts & Boy Scouts

Organization: Nuclear Science Division LBNL
Contact: Alan Poon, AWPoon@lbl.gov, 510-495-2467
Grade Level: 7-12
Funding source: LBNL and supporting funds from foundations

The Nuclear Science Division at LBNL has been hosting the Nuclear Science Day for Girl Scouts and Boy Scouts event annually since 2011. About 200 youths, along with leaders, come to this event each year. Girl Scouts and Boy Scouts in the San Francisco Bay Area learn about the ABC's (alpha, beta and gamma) of Nuclear Science and participate in a number of exciting and educational activities.

The participants have opportunities to construct atomic models, build a simple electroscope, use survey meters to look for hidden radioactivity, tour an accelerator, and also discuss career options with guest scientists. In addition to using Geiger counters in the survey activities, the scouts saw other types of radiation detector in action as well.

Upon completion of the day's activities, all participants get the event patch. Boy Scouts who also complete a prerequisite worksheet will earn the Nuclear Science Merit Badge. This is a very popular community event, and NSD was honored with a community partnership award by a local scout council in 2013.

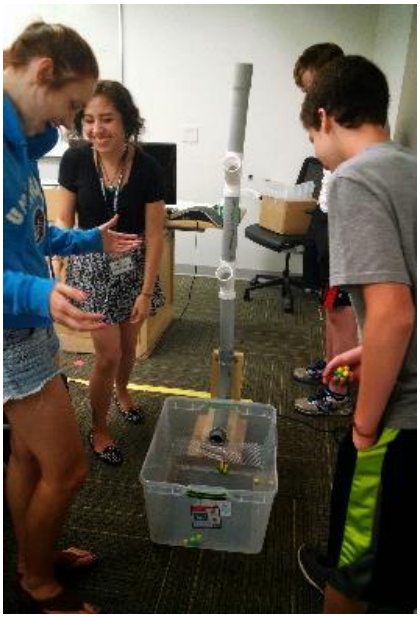
website: http://nuclearscienceday.lbl.gov/

Learn Nuclear Science with Marbles – Lessons & Activities

Organization: Michigan State University
Contact: NSCL/JINA outreach, visits@nscl.msu.edu, 517-908-7363
Grade Level: 6-12
Funding source: MSU/NSF

Modeling nuclei and their reactions with magnetic marbles is an easy way for students to get “hands-on” experience with nuclear science. This model has been adapted for a series of lessons and activities that are appropriate for the classroom and many other venues.

Over 150 teachers have been trained to use these tools, while another 150 have downloaded the materials available freely online. Teachers indicate that this teaching tool is one of the most useful takeaways from their visit to NSCL.



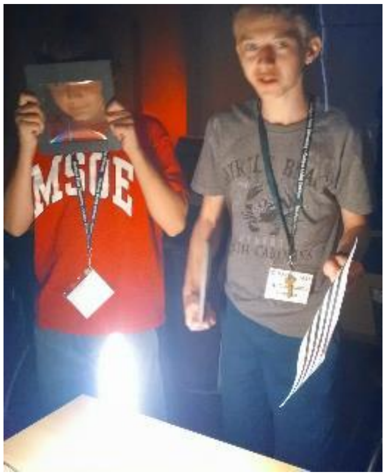
website: http://www.jinaweb.org/outreach/marble/

Nuclear Astrophysics for MST@MSU

Organization: Michigan State University
Contact: NSCL/JINA outreach, visits@nscl.msu.edu, 517-908-6363
Grade Level: 7-9
Funding source: Participant fees

The Math, Science, and Technology Program (MST@MSU) is a two-week residential summer program for academically talented students currently in the seventh and eighth grades. It gives them a chance to dig into some exciting science classes in a college environment. Each day the students take two two-hour classes in astronomy, physics, mathematics, computer science, chemistry, or environmental science. The JINA/NSCL-sponsored Nuclear Astrophysics course concentrates on spectroscopy, nucleosynthesis, and cosmic rays.

Students reported better understanding of the work involved in a research career, more interest in learning physics and greater motivation to pursue physics as a career.



website: http://www.nscl.msu.edu/public

Catch a Cosmic Ray

Organization: Michigan State University
Contact: JINA Outreach, (574) 631-5326, jinaout@nd.edu
Grade Level: 7-12
Funding source: NSF

Catch a Cosmic Ray offers high school tour groups the opportunity to delve into the problem of cosmic rays with a hands-on experiment, form their own hypotheses on the nature of cosmic rays, and test them with directional detectors. This program includes materials for the teacher to use in class before and after visiting NSCL, turning it into a three-day lesson.

website: http://www.jinaweb.org/html/jinaprograms.html

Nuclear & Particle Physics at Ohio University

Organization: Ohio University
Contact: Carl Brune, brune@ohio.edu, (740) 593-1975
Grade Level: 7-17 years old
Funding source: INPP

Young Scholars OHIO
Each year we participate in a two-day workshop for highly gifted students where we highlight research and creative activity at Ohio University. Students and parents attend mini-workshops and participate in activities including a tour of the **Edwards Accelerator Lab** where ongoing research activities are explained to the students.

Faculty members from the **Institute of Nuclear and Particle Physics (INPP)** participate each year. This program is sponsored by Ohio University.

We share our passion to learn about:
stars*novae*supernovae*atomic nuclei *new semiconductor materials *neutron imaging for national security*neutron-induced reactions for future nuclear reactors

"This workshop was life-changing!"
-Young Scholar OHIO participant

website: http://inpp.ohiou.edu/

Nuclear Science Lab Field Trips

Organization: University of Notre Dame
Contact: JINA Outreach, (574) 631-5326, jinaout@nd.edu
Grade Level: 7-12
Funding source: NSF

JINA hosted two schools for field trips to the University of Notre Dame during the Spring for Science Days. This program is part of a concerted effort to increase interest in STEM careers among local students in underrepresented groups.

Within the student body at Washing-ton High School, approximately 75% receive assistance with school lunches and more than 70% are Hispanic, African American, or multiracial. Although the graduate rate is nearly 90%, less than 40% pass the ISTEP. This year, 75 students participated in the 4th annual JINA field trip for WHS. Students toured the Nuclear Science Lab, saw an astronomy presentation in the DVT, talked about careers in physics, and had a team challenge to build ping pong catapults from household supplies such as craft sticks and rubber bands.

Built on the success of the WHS field trip, JINA has hosted the entire 8th grade class from Jackson Intermediate School for the 2nd straight year. Within their student body, approximately 50% are Hispanic, African American, or multiracial, 70% receive lunch assistance, and 25% are in Special Education courses. In addition to the DVT presentation and nuclear science lesson, the students also participated in the catapult challenge and discussed career options with scientists.

Although the DVT and pizza were the favorites for both groups, post surveys and reflections showed that most students appreciated the entire experience.

website: http://www.isnap.nd.edu

Scout Badges

Organization: University of Notre Dame
Contact: JINA Outreach, (574) 631-5326, jinaout@nd.edu
Grade Level: 5-12
Funding source: NSF

JINA has developed a one-day workshop for boy scouts which provides them with all of the information and projects needed to earn their Nuclear Science Merit Badge. So far 4 troops have participated in workshop which includes a tour, building electroscopes and cloud chambers, and lectures on basic nuclear science and career paths. We also often participate in events to facilitate Webelos earning their astronomy badges.

Based on the BSA badge, we have created a girl scout badge, "Getting to Know Nuclear" tailored for young women which covers the same material, but with more societal applications. We held our first workshop for interested girl scouts this fall.

website: http://www.jinaweb.org/html/jinaprograms.html

Nuclear Forensics Investigations Summer Science Academy

Organization: Hope College
Contact: Catherine Mader, mader@hope.edu
Grade Level: High school students
Funding source: Mi-ANS, HHMI

Twenty-eight students and four teachers participated in the Nuclear Forensics Investigations Academy at Hope College. The students did hands-on investigations of nuclear science topics in the context of nuclear forensics applications for 5 days during June.

Topics the students explored included:

- Introduction to nuclear forensics
- Radiation safety
- Detecting ionizing radiation
- Common sources of radiation and measuring background radiation
- Factors that affect detection of radiation
- Gamma spectroscopy as a tool to identify isotopes
- Half-life, decay chains, and dating of nuclear materials

The academies were led by Hope College faculty, high school teachers and Hope STEM education majors. Academy participants interacted with current Hope College nuclear science majors over lunch and learned about the various research areas the students are pursuing. In addition, nuclear science faculty also participate in various activities and share aspects of their current research activities.

website: www.hope.edu/csi

Nuclear Forensics Investigations Teacher Workshops

Organization: Hope College
Contact: Catherine Mader, mader@hope.edu
Grade Level: High school teachers
Funding source: AIP, DHS, APS

The goal of the nuclear forensics workshop program is to provide resources to enable high school teachers to teach nuclear science in a real-world context by

- Providing training, materials and equipment to teachers so they can teach nuclear science in engaging ways
- Providing students and teachers with accurate information on radiation safety
- Encouraging students to consider careers in nuclear science, including nuclear forensics

The lessons provide an introduction to a few basic techniques used in nuclear forensics, and motivate student to learn about nuclear science. The topics were chosen based on relevance to the high school science curriculum, accessibility to hands-on experimentation, and overall classroom suitability. Topics include:

- Introduction to nuclear forensics
- Radiation safety
- Detecting ionizing radiation with a GM tube
- Common sources of radiation and measuring background radiation
- Factors that affect detection of radiation
- Gamma spectroscopy as a tool to identify isotopes
- Half-life, decay chains, and dating of nuclear materials

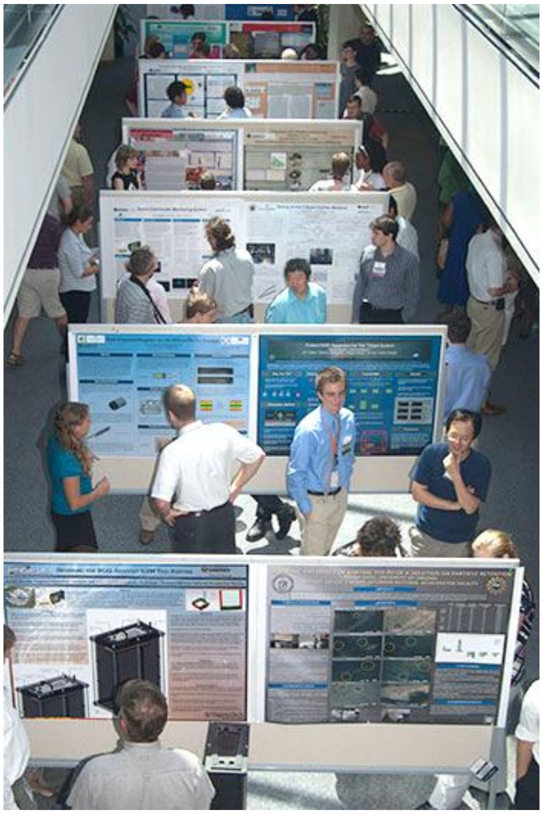
Over the past 7 years, over 100 teachers have participated in workshops ranging in length from 1.5 hours to 16 hours. Over 60 teachers have borrowed equipment kits and utilized the resources provided by the Hope College-led team in their classrooms. Many teachers have borrowed the kit repeatedly over the past 7 years. Several thousand students have been impacted by this project since it began.

website: www.hope.edu/csi

Jefferson Lab High School Internships

Organization: Jefferson Lab
Contact: Jan Tyler
Grade Level: High School
Funding source: Jefferson Lab

Jefferson Lab's High School Summer Honors and the High School Honors Mentorship Programs offer work experience in physics and engineering under the guidance of a Jefferson Lab mentor to the highest-achieving high school students in the local area. The summer honors program is a paid internship, while the mentorship is offered three times each year as an unpaid mentorship.



Students present a summary of their projects to the lab's scientific community at a well-attended lab-wide poster session during the final week of the summer programs.

website: http://education.jlab.org/indexpages/index.html

JLab Science Activities for Teachers

Organization: Jefferson Lab
Contact: Jan Tyler
Grade Level: Teachers
Funding source: Jefferson Science Associates

Jefferson Science Activities for Teachers (JSAT) allows 5th, 6th, and 8th grade teachers to spend four hours per month, on two different evenings, at Jefferson Lab. Each two-hour session includes a Jefferson Lab science-related activity, project, and/or lecture. Teachers are given the materials necessary to implement new strategies into their classrooms. In addition, each session covers material that will be taught in the teachers' classroom in the current nine-weeks grading period. At the conclusion of the program, each teacher receives 32 recertification points to be applied to their Virginia Teaching License renewal. Sixty upper elementary and middle school teachers participated in FY 2014.

website: http://education.jlab.org/jsat/index.html

The Cosmic Connection

Organization: Lawrence Berkeley National Laboratory
Contact: Howard Matis, HSMatis@lbl.gov
Grade Level: High School +
Funding source: DOE

This web site describes a simple cosmic ray detector that can be built by high school teachers and students. This detector can be used to measure the rate, energy and direction of cosmic rays. It can also measure how cosmic rays vary with elevation. In addition, it is a valuable tool to teach elementary measurement statistics. This unit is part of Berkeley Lab's ABC of Nuclear Science online science unit.

Using the information on the web site, many students have built a detector as a senior project and have entered them in science fairs. The web site provides all the information needed to construct the detector.

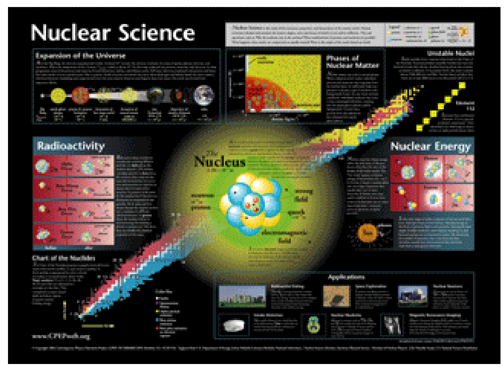
The Berkeley Lab detector has gone to all of the continents of the world; it even went to the South Pole. It has been flown in balloons. It is a good tool to discuss Einstein's principle of time dilation.

website: http://cosmic.lbl.gov

The Nuclear Science Wall Chart

Organization: Lawrence Berkeley National Laboratory / CPEP
Contact: Howard Matis, HSMatis@lbl.gov
Grade Level: High School +
Funding source: DOE

The **ABC's of Nuclear Science** is a brief introduction to Nuclear Science. We look at **Antimatter, Beta rays,** and much more. Visit here and learn about **radioactivity** - alpha, beta and gamma decay. Find out the difference between fission and fusion. Learn about the structure of the atomic nucleus. Learn how elements on the earth were produced.



The website has many resources for teachers and students interested in nuclear science. This includes presentations and a detail guide to nuclear science. A number of activities and experiments are described. There is a section for the Boy Scouts of America Nuclear Science Merit Badge.

The **Nuclear Science Wall Chart** is distributed by the Contemporary Physics Education Project (CPEP) is a world wide, non profit consortium of teacher educators and physicists. The chart explores the structure, properties and interactions of atomic nuclei; it describes basic nuclear processes and the modern picture of the nucleus and then applies them to the formation of the Universe. It illustrates the known isotopes with a chart of the nuclides in graphic form, traces radioactive decay from alpha to gamma and shows how new elements are found. Many nuclear science applications are described. The CPEP website describes several ways that that that the Nuclear Science Wall Chart can be obtained.

websites: http://abc.lbl.gov
http://www.CPEPphysics.org

Physics of Atomic Nuclei @ MSU

Organization:	Michigan State University
Contact:	NSCL/JINA Outreach, pan@nscl.msu.edu, 517-908-7363
Audience:	Science Teachers and High School students
Funding source:	NSF

Physics of Atomic Nuclei @ MSU hosted 24 high school students and 17 science teachers from around the country in its 21st year. Over the course of two one-week programs, participants attended talks by faculty regarding current research in nuclear science and astrophysics, performed calibrations and experiments with a neutron detector, and presented their findings through a poster session or lesson plan (for the teachers).

Students were expected to evaluate their interest in science/research careers. Significant gains were reported in:

- understanding of what those careers are like and how to prepare for them
- Interest in physics major
- Excitement and confidence for college
- Desire for careers in physics/astronomy

"This program shattered my expectations… I also loved how we got to work with equipment that physicists used as well as interacting with physicists."

Teachers focused on updating their knowledge and finding ways to incorporate topics in their classrooms. They reported increased interest in and comfort with teaching nuclear science and astrophysics.

"It's been 20 years since I have thought about nuclear physics this deeply; I like it this time!"

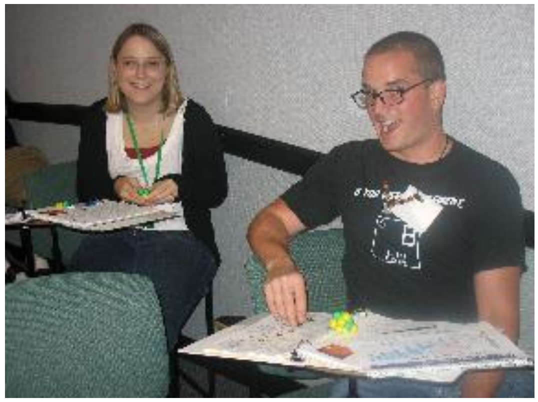
website: http://www.jinaweb.org/outreach/PAN/

Professional Development for Teachers

Organization: Michigan State University
Contact: NSCL/JINA Outreach, pan@nscl.msu.edu, 517-908-7363
Audience: Science Teachers
Funding source: NSF

Outreach personnel from NSCL and JINA often attend conferences (or set up individual workshops) to train science teachers who want to incorporate nuclear astrophysics in their curricula.

These professional development events put expertise, equipment and resources in the hands of teachers who directly touch the lives of thousands of students. Maximizing the teachers' interest, comfort and excitement related to nuclear science topics is a very efficient way to connect with many future scientists.



website: http://www.jinaweb.org/outreach/PAN/

Physics of Atomic Nuclei @ IMSA

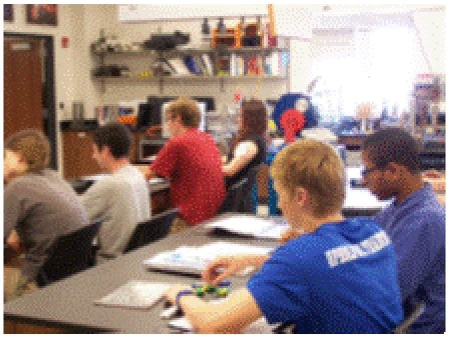
Organization: University of Notre Dame
Contact: JINA Outreach, (574) 631-5326, jinaout@nd.edu
Grade Level: High School
Funding source: NSF

The **Physics of Atomic Nuclei (PAN@IMSA)** program is held at the Illinois Mathematics and Science Academy in Aurora, IL during their intersession week, and modeled after the programs at MSU and ND. IMSA is a 3 year residential school for students gifted in math and science. Intersession is a chance for students to study new topics taught by alumni and faculty. Choices range from robotics to time travel in science fiction. The students learned nuclear astrophysics through lectures and discovery based experiments similar to the MSU and ND programs. However, since the program doesn't take place at a lab, the experiments are designed with portable detectors. Students learned skills such as soldering and computer-detector interface before assembling their own Geiger counters, which they used to measure the effect of distance on radiation flux. They used an MSU CRD to determine the effect of angle on cosmic ray flux, and used a QuarkNet CRMD to measure the lifetime of the muon and to "discover" time dilation. 40 students have participated over the last 3 years.

website: www.jinaweb.org/outreach/PAN

Physics of Atomic Nuclei @ Notre Dame

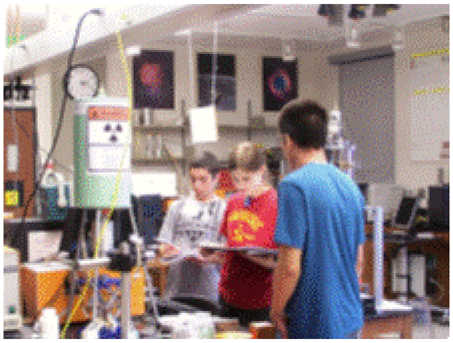
Organization: University of Notre Dame
Contact: JINA Outreach, (574) 631-5326, jinaout@nd.edu
Grade Level: High school
Funding source: NSF



Physics of Atomic Nuclei @ Notre Dame (formerly PIXE-PAN) hosted 15 high school students from 9 different states in its 6th year. Over the course of the week, students were presented with lectures by faculty in nuclear physics and astrophysics, performed modern lab experiments in the state of the art Jordan Hall of Science, and presented their findings in a poster presentation to parents and members of the physics department.

The students entered the program with a high interest in science, and nuclear astrophysics in particular, and their interest remained high after. However, gains were seen in their attitudes towards basic nuclear research, and an understanding of what a career in research entails.

"I am really much more interested in nuclear science in general now"



The average score on the knowledge test, which covered lecture material as well as experimental concepts, rose from 47% to 73% after the week-long program. The students also found the program immensely enjoyable.

"Learning with a group of peers interested in science the way I am was one of the best educational experiences I've had so far"

website: www.jinaweb.org/outreach/PAN_ND/

Richmond Physics Olympics

Organization: University of Richmond
Contact: C. Beausang
Grade Level: High School
Funding source: University of Richmond

To stimulate interest in physics among high school students and to provide support for physics teachers in the region, the Department of Physics organizes an annual Physics Olympics competition. The daylong event is held on campus; inside, outside and around the Science Center on a Saturday in the spring, once the weather gets nice! The Richmond Physics Olympics has run annually since 2005. Each year we attract 60-100 high school students and teachers from schools all over Virginia. About 40 Richmond undergraduates help staff the event each year.

The overriding theme of the Richmond Physics Olympics is that 'Physics Is Fun'. The aim is to bring high school juniors and seniors (including inner city and/or underprivileged students) into the university atmosphere for a day. During this time they compete as a four-person team in a variety of physics-based experimental events. A volunteer staff, drawn from the faculty, staff, and undergraduate students of the physics department judges these events. The idea is not to intimidate the students by asking them to solve hard theoretical problems but rather to encourage them to enjoy science by letting them apply common sense ideas, team work and basic physical concepts to make measurements, complete the various events, and win prizes. Our experience is that the participants enjoy themselves while applying basic ideas from physics to real world situations. Hopefully they also learn some new physics while interacting with members of the physics department faculty, staff and students.

The competition takes the form of a pentathlon, consisting of five thirty-five minute events. Each event is a task or simple experiment, which the students perform as a team and for which they obtain a result or measurement. The teams are ranked based on the closeness of their result to the correct one (as defined by the judges!). A physics general knowledge quiz is also held throughout the day. The experimental apparatus is deliberately kept very simple, rarely rising far beyond meter sticks, buckets of water, and batteries (equipment budget each year is only ~$200). The idea is to encourage innovative thinking and to illustrate that, sometimes, quite remarkably accurate measurements can be made using the simplest apparatus. Most of our budget (~$4000 per year) is spent on tee shirts for all participants, lunch, snacks, and prizes.

Center for Accelerator Science

Organization: Jefferson Lab
Contact: Hari Areti
Audience: Undergrad/Grad
Funding source: Jefferson Lab, Old Dominion University

In 2008, Jefferson Lab partnered with Old Dominion University to found a Center for Accelerator Science in the Physics Department at ODU. The Center offers a spectrum of research opportunities for outstanding undergraduate and graduate students in accelerator sciences and technologies. The students have access to state-of-the-art facilities at both ODU and Jefferson Lab. It has grown to seven professors, two Jefferson Lab professors, one postdoctoral fellow and 11 graduate students with grants totaling $6.5 million. To date, six students have earned their Ph.D.s through the Center.

website: http://www.jlab.org/accelerator-center.html

Majorana Collaboration Mentoring of Young Members

MAJORANA

Organization: Majorana Collaboration
Contact: Vince Guiseppe, Guiseppe@mailbox.sc.edu
Alan Poon, AWPoon@lbl.gov
Audience: Graduate student and Postdocs

The MAJORANA collaboration has a mentoring committee that consists of two senior and two young (post-docs or graduate students) members of the collaboration's executive committee.

The committee provides career counseling for post-docs; ensures that post-docs participate in the preparation of grant proposals and renewals for Majorana; coordinates with the presentation committee to ensure that junior members present their work at conferences; and organizes mentoring activities during collaboration meetings.

In the past four years, the Mentoring Committee organized the following activities for the young members:

- video conferencing with a member of a faculty search committee to get his insights of the completed search process.
- virtual career planning workshop conducted by a career development professional.
- video conferencing with a recruiter for high-tech start-ups
- "brown-bag lunch" with individuals who have successfully transitioned from a post-doc into a career position in industry or academia.
- "brown-bag lunch" with senior members of the collaboration to discuss outlook of the field, and strategies for getting funding as a junior faculty.

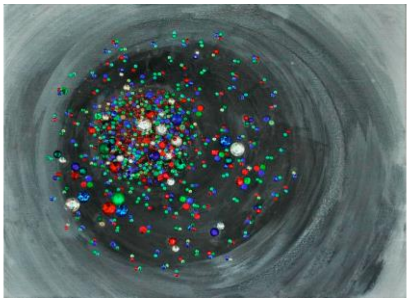
Science and Art Collaborations at the Pratt Institute

Pratt

Organization:	Pratt Institute
Contact:	Ágnes Mócsy, (917) 209-1516, amocsy@pratt.edu
Audience:	Undergraduate
Funding source:	Partially funded by Brookhaven Science Associates

Since joining the faculty at Pratt Institute in 2008, Professor Mócsy has reached out to Pratt students to form collaborations between artists, designers, film-makers, writers and architects to introduce them to the science of RHIC: “When we make our physics accessible, great things can happen. When physics meets art, really great things can happen.” Her vision and these collaborations have produced a variety of highly engaging works that educate and inspire the students, the public, and the scientists.

“Glamorous Gluons” an art exhibit by Sarah Szabo is an example of a notable project: “By creating the artwork, it’s a way of better understanding what I learned. It’s part of the process; artwork is about my gaining of knowledge. I feel like I can make the art better if I really know what the topic or object is.”



So far projects have involved over a dozen Pratt students from a variety of non-STEM fields. The impact on the students has been profound changing the course of their lives: one student became a physics major, and another chose to become a science writer. The impact will continue to spread as these students infected by this enthusiasm for science pursue their interests in diverse fields but with a new perspective and appreciation for science.

website: http://www.agnesmocsy.com/#!student-collaborations/c10bu

Davis-Bahcall Scholars

Sanford Underground Research Facility

Organization: Sanford Underground Research Facility
Contact: Peggy Norris, pnorris@sanfordlab.org, (605)-722-5049
Audience: Undergraduate
Funding source: 3M Corporation, NASA SD Space Grant Consortium, NSF EPSCoR

The Davis-Bahcall Scholars is a program that introduces future STEM professionals from South Dakota – entering college freshmen and sophomores – to modern science and engineering research, with an emphasis on the big physics experiments taking place in underground laboratories.

The annual program, four to five weeks in duration, has variously included international and national travel experiences and extended periods at Sanford Underground Research Facility, Department of Energy national laboratories and research universities. Since 2009, 88 students have participated in the program and more than 40 have now graduated, 95% in STEM fields. Alumni at the program have interned with physics groups at Sanford Lab, University of California Berkeley, Argonne National Lab and University of Notre Dame. At least five graduates are attending graduate school in physics at universities around the country.

website: http://www.sanfordlab.org

Research Experience for Undergraduates at Texas A&M

Organization: Texas A&M University
Contact:: S. Yennello
Audience: Undergraduates
Funding source: NSF & TAMU

The Cyclotron Institute has hosted a Research Experiences for Undergraduates programs every year since the Summer of 2004 for approximately 12 students/yr. The REU program provides nuclear science research experiences for those who cannot get them in the normal course of their undergraduate program.

All students engage in nuclear science research projects at the Cyclotron Institute. Additionally the students are exposed to the broader field of nuclear science through weekly faculty lectures. They are informed about career options and societal applications during career day. At the end of the summer the students present their research projects in a Cyclotron Institute symposium and a campus-wide poster session. Additionally many of the students present a poster at the fall meeting of the Division of Nuclear Physics of the APS.

Emphasis is on recruiting students from schools that do not offer these types of research opportunities.

website: http://cyclotron.tamu.edu/smp

Nuclear Science at the University of Rochester

Organization: University of Rochester
Contact: W. Udo Schroeder, (585)275-8263, schroeder@chem.rochester.edu
Audience: Undergraduates, High School
Funding source: DOE, NRC

The University of Rochester (UR) Departments of Chemistry and Physics & Astronomy support basic and applied research in nuclear science. Graduate and undergraduate training includes several lecture courses and the 1-semester advanced nuclear science education lab ANSEL which is offered every year.

The ANSEL provides students with hands-on experience in detection of radiation in our environment, nuclear instruments and methods, and applications in nuclear forensics.

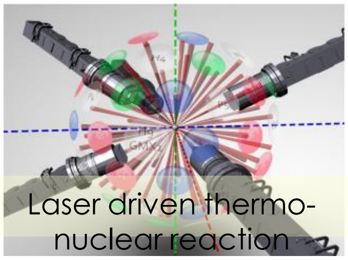
The nuclear science research group (NSRG) conducts an experimental and theoretical research program in basic nuclear science, nuclear and radiation chemistry, and detector development.

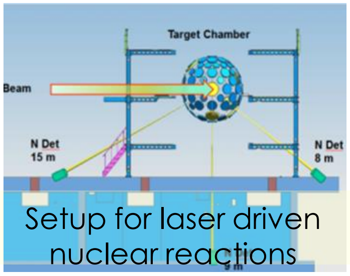
The major on-campus nuclear facilities include some of the world's most powerful laser systems Omega/EP at the UR Laboratory for Laser Energetics (LLE). While most of the LLE research and technical R&D focuses on problems associated with laser driven inertial fusion energy, the powerful laser systems are now also employed in novel nuclear science experiments conducted by the NSRG. The experiments use both, laser driven particle beams and thermonuclear plasmas, which are thought to emulate certain stellar environments.

The LLE and, on smaller scale, the NSRG routinely provide research internships for under-graduates and local high schools students.


Students in ANSEL Lab


Students in NSRG Lab


Laser driven thermo-nuclear reaction



Setup for laser driven nuclear reactions

websites: http://nuchem.chem.rochester.edu/index.html
http://www.lle.rochester.edu/about/education/high_school_program.php

Applied Radiation Physics Certificate Program at UW

UNIVERSITY of WASHINGTON

Organization: University of Washington
Contact: Alejandro Garcia
Audience: Medical or bioscience systems technicians or engineers, medical paraprofessionals.
Funding source: University of Washington

Students from our professional and continuing education program and from our evening masters program take this class to get practical training in experimental physics and satisfy their curiosity about nuclear science. They want to learn nuclear physics, from the basics to the applications.

This class is part of a three-quarter program called *Radiation Physics: sources, detection, imaging, and safety* that includes two other sections on imaging and on uses of scintillators.

Lab experience: students tune beam through the accelerator, learn high-vacuum techniques, electronics, accelerator physics. The photo above shows a group of students near a target chamber getting ready to deliver beam. The photo on the left shows a group of students in the process of acquiring data.

website: faculty.washington.edu/agarcia3/phys575/