A Study of the Need for a Nuclear Minor Program at WPI

An Interactive Qualifying Project

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1. Abstract

The goal of this project is to examine the need for a nuclear science minor program at Worcester Polytechnic Institute. Beginning with a review of WPI's previous nuclear program which focused solely on power generation, and continuing with a look at the current state of nuclear science, it was found that that a multidisciplinary academic program would benefit the students of WPI. The current state of nuclear science was looked at through a study of current research trends in nuclear science, applications of nuclear science in different fields and nuclear science programs of other universities.

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3. Introduction

"The results of these discussions may include proposal for new courses and new programs including a "Nuclear Minor"."

~From the November 2000 Faculty Meeting minutes, when the Nuclear Program was dropped. *http://www.wpi.edu/Campus/Faculty/Meetings/0001/Agendas/111600cao.txt*

The goal of Worcester Polytechnic Institute is to "create and convey the latest science and engineering knowledge in ways that would be most useful to the society from which its students came."[1] In order to meet this goal WPI must adapt its curriculum to best meet the technological demands of the present society. In order to maintain a curriculum that addresses current scientific and engineering needs WPI must look at the trends in past and current industries and to foresee the future of these industries. In order to meet its goal WPI must look at current uses of science and technology, it must look at research and development in laboratories and universities, it must look at what competing universities are doing to be successful, and it must offer a curriculum to its students that will ably prepare them to work in the field of their choice.

The addition of a multidisciplinary nuclear science minor program to the WPI curriculum will help the university to achieve its goal. In today's society nuclear science is used extensively in many professional fields. Nuclear science is heavily used in medical imaging and therapy. Nuclear power is a major source of electricity, totaling over 20% of the US's power generation. Nuclear Science is used to sterilize food and medical products. Many experiments dealing with atomic particles require knowledge of nuclear science. The field of nuclear science is thriving; current research shows many great potential uses for nuclear science including nondestructive cancer therapy, more efficient and safer power generation through fission and fusion, and advanced methods for dosimetry and imaging/analyzing materials.

Nuclear science will lead to advancement in many fields, and nuclear scientists and nuclear programs stand to benefit greatly. Competing schools (universities similar to WPI) have very successful nuclear science programs that carry out research in all areas of science and engineering. There is a demand for professionals with knowledge of nuclear science.

A nuclear science minor program would allow WPI to continue to create and convey the latest in science and technology. Nuclear Science is a large and growing field that is constantly contributing to the expansion and development of many disciplines, and students of all disciplines stand to benefit from the creation of a nuclear science minor program.

4. History

"This greatest of all destructive forces can be developed into a great boon, for the benefit of all mankind."

~President Dwight D Eisenhower, December 1953 address to the Untied Nations

4.1 History of the WPI Nuclear Program

WPI has had a Nuclear Reactor on campus since the 1950's, and has offered a program in Nuclear Engineering until November 2000, when the Nuclear Program and all nuclear classes were voted to be stricken from the course offerings for the next academic year. For over 40 years WPI taught the expanding world of nuclear sciences. The rationale began in the 1930's and 40's, with 'The War To End All Wars'.

4.1.1 The AEC and the NRC

In August of 1945 The United States used nuclear weapons for the first and only time in warfare. The "Last Great War", World War II, and the scientific developments that arose as a need for bigger and better weapons ushered the world into a new era. Starting with the destructive power unleashed over Japan 56 years ago, we have entered into the Nuclear Age. Soon after the end of the war, tensions with the USSR began to influence the path that nuclear technology followed. Despite agreement of political, scientific, government and business leaders that peaceful applications of nuclear power were possible and should be explored further, the beginning of the Cold War was focused on weapons race and the destructive power of this new science. Both the United States and the Soviet Governments took the initiative into expanding their knowledge of the power of the atom. In the United States, the government established control through legislature it passed and agencies it created.

The beginning of the Nuclear Age in the United States, a time of fast and furious technological development, was regulated by the Atomic Energy Commission (AEC). The AEC was enacted in 1946 as a five-member council dedicated to government control of nuclear power and technology. The Atomic Energy Act (AEA) of 1946, which set up the AEC, did not allow for private commercial applications of nuclear technology. The purpose of the AEC was to maintain strict control over atomic and nuclear technology and to explore and exploit its benefits solely for military purposes. Thus, societal benefits of the new technology were put aside at first in order to explore solely the destructive power of the nucleus.

The 1946 AEA stood for 8 years, until the 1954 Atomic Energy Act was passed by congress. This legislation allowed for commercial applications of nuclear power for the first time. It abolished the monopoly that the government had enjoyed for nearly a decade, and changed its goals to a more commercial and public mission. It continued the weapons program as one if its main goals, but also attempted to promote the private use of atomic energy, allowing society to enjoy the benefits of nuclear power, and not just to fear its destructive power. A new issue had also developed, which the AEA of 1954 attempted to address. The third part of its mission was to protect the public health and safety from the dangers of fallout, radiation, and radioactive waste. Thus, the 1954 AEA made the AEC the research, regulating, and policing commission of the government.

This near-total power of the AEC meant it had no one to answer to, and soon it was apparent that it could bend its own rules in order to accomplish its goals. Because one of the primary goals was promoting the commercial sector of nuclear power, the AEC pushed hard to get utilities to build power plants. Political leaders saw the possibility for atomic energy to be a great benefit to society, such as President Dwight D Eisenhower. In a December 1953 address to the Untied Nations, Eisenhower said that "this greatest of all destructive forces can be developed into a great boon, for the benefit of all mankind."

To begin promoting nuclear power, the AEC announced a "power demonstration reactor program" in January of 1955. This program established many things, such as the research and development of nuclear power generation at National Laboratories, subsidies for private industries to do their own research, and financial exclusion for a seven-year period for fuel use charges established for the loan of fuel, which the AEC would maintain ownership of.

4.1.2 The WPI Nuclear Reactor Facility

With all of the research into power plants going on there was much studying of reactor physics. Non-power reactors were primarily built at Universities and other institutions, many on AEC grants, to provide research and training for nuclear engineers. The AEC sponsored and funded these "Training and Research Reactors" because a core of nuclear engineers was needed to continue the race to further develop this new technology. The WPI Nuclear Reactor Facility, located in Washburn Shops on the Worcester Polytechnic Institute Campus in Worcester, MA, began construction in 1958 with a $150,000 grant from the AEC given in June of 1958. General Electric was contracted to construct the open pool reactor that was initially licensed for 1 kW (thermal). By 1959, it was granted permission to begin operations, and its primary goal was as a tool for nuclear engineering education. On the night of December 18th, 1959, the WPI reactor first reached criticality.

The mainstay of the WPI Nuclear Engineering Program, the WPI Reactor has gone through several changes over the past few decades. In 1967, the output was raised from 1kW (thermal) to 10kW (thermal). In 1983 the license was extended for another 20 years. In 1988, the facility became only the second in the country to convert to low-enriched uranium fuel as mandated by the NRC (Nuclear Regulatory Commission, the replacement of the former AEC). But now nationwide, there is a drop in Nuclear Power interest, and this has caused the WPI Nuclear Engineering Program to become smaller. WPI is not alone – nationwide other institutions are faced with the same problem; where to go from here with their Nuclear Engineering Programs.

The United States was regarded as the early leader in Nuclear Sciences, although now it is seen as a nation falling behind. New areas besides power are becoming present as new applications of nuclear science, and the Nuclear Reactor remains the only source of high neutron flux. The US Government operates only two test reactors supporting the sciences currently. In the 1970's, there were about seventy (70) University Research Reactors. However, in 2000 that number was down to twenty-nine (29). Despite their initial uses for power generation and research, Nuclear Programs and Nuclear Reactors have much more use in today's society than just power. How has WPI utilized its reactor and, more importantly, its nuclear engineering program, in the past years?

4.1.3 The Nuclear Engineering Program

The reactor and its associated Major Program have been aimed at teaching the principles of power generation, reactor physics, reactor operations, waste management, and other purely engineering and power oriented applications. A large number of Electrical Engineering students have, over the past 10 years, shown an interest in Nuclear Engineering courses. Control systems for reactors are the connection between the Electrical Engineering students and the Nuclear Technology. However, other applications such as medical therapy, medical imaging, nuclear physics, radiochemistry and radiobiology, health physics, etc; have not been considered by the program or its classes. The Nuclear Engineers bred by WPI over the past years have been ready to go into the power generation field and none other.

4.2 The 1990's

A glance at the number of students taking Nuclear Engineering courses since the 1988-1989 academic year shows variation in enrollment, going from a total enrollment in all NE classes of 30 in 1988-1989 and 1989-1990, then jumping for the next 7 years into a range of 43 and 68 per year, as seen in Appendix A page 1-2. After that the enrollment once again drops to 29-31 for the next 2 years (1997-1998 and 1998-1999), and then drops to the range of 10-15 for both the 1999-2000 academic year and also this current 2000-2001 year.

This shows a moderate enrollment over the past 10 years. The numbers are variable, with an apparent 'hay day' for the program in the 7 year stretch from the 1990-1991 to 1996-1997 academic years. However, the data becomes more interesting when broken down into more detailed data.

The courses can be thought of as basically lower-level and upper-level courses. NE 2001, NE 2002, NE 2011, NE 2012, and also ES 2011 are considered lower level. A look at the enrollment in these courses year to year shows more consistent student interest. The range from 1988-1989 to 1988-1989 shows an average of more than 26 student enrollments per year, with a range in the data from 16 to 39. However, when looking at the enrolled students major we can see that of these approximately 26 students, only 42% were Mechanical Engineering majors (Appendix A, page 17) This means that for lower level courses more than half of the student enrollment came from non-ME's. This shows that although the Nuclear Engineering program was under the Mechanical Engineering department for these years, most of the students taking courses were NOT on the ME/NE path.

The courses could have been taken as general engineering courses, or as the 'Nuclear Tech Pack" option for Biomedical Engineering students, or just so satisfy a student's personal interests in the field. Either way, there is a strong interest in Nuclear Engineering over the past 10 years, not just in the ME department, but also in other departments. These students do not go on to major in Nuclear Engineering, or anything related to Nuclear Sciences, and thus do not show up as ‘active interest’ in a nuclear program, despite their apparent initial interest in the field.

It can further be shown that the upper level courses, which are the purely power generation oriented courses which would hold little or no credit value for a non-ME major, lack this strong outside interest. Over the same span for the lower level courses, the upper level courses have a similar, but slightly smaller average – around 20. However, nearly 64% of the students enrolled in these courses were ME majors. In fact, over the given time range, in no year did the number of non-ME students outnumber the ME students in upper level courses, whereas only in 3 out of the 11 years did the ME majors outnumber the others in the lower-level courses (Data found in Appendix A, page 18). This is clearly a student interest slighted by a lack of a multidisciplinary program to incorporate more of the interest. The average number of non-ME majors taking NE classes over this span dropped from 15 to 5. There is at least 10 students per year who may have gone on to take more upper level classes but who could not because of a lack of a program.

Also hurting the program throughout the1990’s was its constantly changing academic faculty. With retirements, and faculty position changes, there were almost as many instructors as there were classes for the mid to late 1990’s. Professor Leslie C. Wilbur, who was at WPI since the creation of the Reactor Facility in 1959, retired, and was replaced with new staff members. These new full time faculty and staff members, Prof. John Mayer and the Reactor Facility Director Leo Bobek both left WPI, and were not replaced with full time faculty replacements, only with a faculty member Stephen LaFlamme, who is the current Director of the WPI NRF. This left the facility and program undermanned, with no tenure-track faculty members on campus. This means that all the teachers for the nuclear classes in the past 2 years have been from other schools, and have created inconsistencies in the material covered in the introductory courses.

The number of students that still went through the program during these times of unraveling is a tribute to the strength of interest in such a program.

The focus solely on power generation was clearly constraining the type of Nuclear Engineer that WPI can educate. Nuclear Science is a large part of today's society and technology, but only one small part was addressed by the program of the past decade. The program is a relic of the 1950's initiative to build this nation's nuclear infrastructure. The last plant licensed to be built was in 1975. After Three Mile Island and Chernobyl the Nuclear Power Industry has hit a no-growth period. The nuclear interests of the nation shifted to other applications, while the WPI academic program did not. Thus, the WPI Nuclear Engineering Program ignored the interest of all non-ME majors, who actually outnumbered the Mechanical Engineers interested in learning more about nuclear science, and subsequently when the Power related interest dropped, or rather shifted to other fields, the number of WPI Nuclear Engineers dropped when there was no place for the interest to shift.

5. A Need for Change

> "University research and training reactors must establish a multi-disciplinary infrastructure in order to strengthen their position within the university."
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> *~Pedro B. Perez, Chairman, TRTR; Professor, NCSU; from:* University Research Reactors: Contributing to the National Scientific and Engineering Infrastructure from 1953 to 2000 and Beyond; *A Report to NERAC Subcommittee to Analyze the Future of University Nuclear Engineering and Research Reactors*

5.1 WPI's Changes

There is a need for change in the Nuclear Sciences at WPI. The program of the past years has lacked student and faculty interest. The Nuclear Sciences and Engineering have been put on the back burner and stayed 'out of people's minds.' It was allowed to fade away into just a shell of a program. How did this happen? And why? America on the whole has had a declining interest in Nuclear Power for a long time. WPI's program was aimed at nuclear power, and so when national interest dropped, so did student and faculty interest, not just at WPI but across the country as well.

The reason for the decline in numbers here at WPI is simple. Students gain nothing from taking nuclear courses beyond the basic introductory courses. All upper level courses have focused on Power Plants, Reactor Physics, Radiation Waste Management, etc. Students with an interest in medical imaging, food irradiation, or any other non-power topic would only learn useful information from NE2011 and 2012. Thus, the upper level courses only interested those who wished to go into a Nuclear Power Career.

5.2 National Trends

When it is said that interest in the Nuclear Program has declined, the real fact is that interest in nuclear power generation has declined, a national trend. The American Nuclear Society, a Power-Oriented group of Engineers, Students, Researchers, Professors, and Scientists, draws 1100-1500 people to its annual meeting. The Society of Nuclear Medicine typically draws 15,000; The Radiological Society of North America draws 60,000 people to Chicago each year.

Overall, as the nation changed to non-power applications, WPI lost its focus on the latest trends in the field and thus lost its students. By the end of the 1990's, the WPI program offered nothing of interest or use to non-ME majors. We say that this is because WPI did not offer other aspects of nuclear technology. Looking at current applications of nuclear technology to see which fields are using it will help show what kind of students nuclear science will be useful to.

<u>6. Current Uses of Nuclear Technology</u>

> "Technological advances spurred by the demands of nuclear research have led directly to the creation of research and analytical tools in fields ranging from medicine and environmental science to art and archaeology."
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> *~University of Wisconsin, Madison Nuclear Physics Brochure.*

The WPI Nuclear Engineering Program has been aimed mainly at Power Generation, and has suffered in recent years with the declining nationwide interest in this area. However, Nuclear sciences cover more than Nuclear Power Generation. The important question is really not what happened in the past but an analysis of the current situation of nuclear science in today's society.

Nuclear Science has numerous applications in many fields. It can be made use of in agriculture to speed the breeding of enhanced crops, which could reduce the need for fertilizers and consume less water. Medicinal uses include sterilization of medical products, drug testing, and medical imaging. Neutron activation analysis can determine the elemental composition of materials. Improved electrical components can be created through neutron transmutation doping of silicon. And those are just a few of the uses of nuclear technology. In fact the American Nuclear Society has 19 professional divisions, and there are over 60 official societies and organizations in the radiological sciences worldwide.

6.1 Medical Uses

Nuclear science is responsible for great developments in the medical field and is being used more frequently by more professionals. The clinical applications of radiation are usually either for diagnosing a patient to gather information about the structure and function of internal systems, or for therapeutic uses, treating cancer and malignant growths both on the surface and internally.

6.1.1 Imaging Uses

Recently nuclear science has led to the development of different diagnostic methods to analyze organs and other structures using different imaging techniques. Dynamic imaging, radionuclide thyroid imaging, and nuclear magnetic resonance imaging are three particularly new and practical methods that can provide detailed 3D information for biologists, physicians, chemists, and many other professions.

Dynamic imaging is a medical technique that creates an image from using special cameras to follow the flow of a radioactive tracer element introduced into the patient. By studying the flow the flow of the tracer, physicians can determine functionality of certain organs, internal biological activity, and other events within the body. The most common applications of dynamic imaging are currently for studying the renal system, heart functionality, brain metabolism, and liver studies.

In the renal system dynamic imaging is used to measure the rate of blood filtration through the kidneys (the glomeruler filtration rate). This provides a direct quantitative measurement of the kidney performance, which aids physicians in recognizing kidney problems and administering appropriate treatment.

Dynamic imaging of the heart measures the amount of 'cardiac shunting' where blood, after leaving the heart, takes a shortcut back into the heart without first cycling through the body. Shunting is the result of a defect in the atrium or ventricle. The information gathered from imaging will provide physicians with the means to better plan treatment for patients.

Dynamic studies of the brain are common using nuclear imaging techniques. With imaging we can 'see' the brain metabolizing a glucose substance introduced into the system, the more active sections of the brain metabolize the glucose at a higher rate. This allows scientists and physicians to observe the effects of the brain on different local stimuli. This will prove to be a valuable tool in the study of the workings of the human brain, which is a very large scientific field that still has a lot to discover.

Currently the most widely used technique of dynamic imaging (and presently the most economically feasible method) is the planar imaging method of single photon emission computed tomography, SPECT. SPECT collects a series of images from a gamma camera as a radioactive tracer, injected into the system of interest, makes its way through the system. The images are taken from different angles and compiled together to provide information on the workings of the system.

Another method of dynamic imaging is positron emission tomography, PET. This is similar to SPECT, except the data collector is circular and surrounds the patient so the information can be gathered for all angles all at once and a detailed 3D image can be created. This technique provides a better idea of what is happening instantaneously in the body, but is also very expensive.

Image based dynamic SPECT is another method currently being researched and developed. It is like SPECT except that its camera moves around the patient. This provides information for a real 3D model (instead of superimposed 2D images). Often the detector has multiple cameras at different angles so it does not have to move as fast or as much. This technique is especially promising for it is far less expensive than PET but provides more information than standard SPECT techniques.

A similar imaging method is radionuclide thyroid imaging. Here a tracer is introduced to the system. After a few minutes a scan is taken of the thyroid (which absorbs some tracer), and then another one the next day. It provides information on the functionality of the thyroid as well as its size and position. This is an easy process and more convenient for the patient, and gives the physician important information for their diagnosis.

Nuclear magnetic resonance imaging, NMRI, is an analytical technique used for determining the content, purity, and molecular structure of a sample. NMRI can be used to quantitatively analyze mixtures of known compounds or it can be used to match samples with unknown contents against known spectral libraries to determine its content, or in can deduce the basic structure of the sample directly. It gets its information from the difference in energies of nuclei with different spin (which act like magnetic dipoles) in an electric field. The energy differences correspond to radio frequencies, so certain nuclei will absorb and emit radio waves of certain characteristic frequencies. NMRI is also a great technique for observing soft biological tissue and along with CT (computed tomography) it can provide thorough and detailed anatomic models.

Nuclear science has provided imaging techniques of great value to many fields. Biologists and physicians can readily observe the workings of a biological system and diagnose irregularities and problems without having to use intrusive methods. Chemists can determine the makeup of almost any substance, and certain molecular properties can be easily identified with techniques relying on nuclear technology. Since the development of practical nuclear imaging in the 1970s its uses have grown rapidly. Today nearly all cardiac patients receive a SPECT scan, and many other physiological abnormalities are being diagnosed regularly with nuclear imaging, and progress in these areas continues almost daily.

6.1.2 Therapeutic Uses

The therapeutic applications of nuclear science are almost entirely used for the treatment of cancer. External lesions can be treated best by low-penetration radiation aimed directly at it. Internal tumors require penetrating radiation though, usually high energy x-rays or gamma emitting radioisotopes. With this treatment there is a concern over killing the cancer cells without harming the other cells. Some methods for accomplishing this are doing the treatment over a period of time so that the body's healing mechanisms will help, and also doing the treatment from different angles so that the cancer cells receive much more radiation than surrounding cells. One of the most promising developments in this area is that of boron neutron capture theory, BNCT, which successfully destroys cancerous cells while leaving neighboring cells largely unharmed.

BNCT is a two-part process. First a compound containing atoms of boron is injected into the patient. The boron becomes highly concentrated in the cancerous cells but not in the healthy cells. Next the tumor is irradiated with neutrons; the neutron radiation is virtually harmless and passes right through the tissue unless it comes in contact with boron. When a neutron collides with a boron atom an alpha particle is emitted, the alpha particle is destructive radiation, but only travels a distance of about one cell length. Thus only the surrounding cancer cell is destroyed. This is an incredibly valuable treatment. Further development of BNCT will lead to a powerful, non-surgical, treatment for cancer that will make life easier for both patients and physicians.

Nuclear science clearly plays a substantial role in medicine, providing beneficial methods of diagnostic and therapeutic nature. Professionals with knowledge of nuclear science will be able to further advance these methods as well as open new unexplored areas of nuclear medicine.

6.2 Power

One of the largest roles of nuclear power is the energy contained inside the nucleus of an atom which, when split, is released. Also, nuclear decay can provide a consistent source of energy and power. One of the first and still most prominent use of nuclear science is power generation, whether on land, at sea, in space, or even in the human body.

6.2.1 US Navy

Even though nuclear power had its 'hay-day' and is now in a no-growth period, there is still a need for engineers who know how nuclear power works. One of the top reasons is defense. The United States Navy has many aircraft carriers and submarines with nuclear reactors as their source of propulsion and power. There are currently 12 Aircraft carriers in service and a 13th, the Ronald Reagan, under construction. Of these 13, 9 are powered via nuclear power. On 8 of these there are 2 Reactors per ship, which the 9th, the USS Enterprise (CVN 65) has *eight* nuclear reactors powering her. Also for the large number of nuclear powered Submarines, both "fast attack" submarines and "Boomers", or missile subs, the Navy needs nuclear trained students. Recently, with Nuclear Engineering Programs across the country in the decline, the Navy has taken an active role trying to support those programs that are still active, with the help of the US Department of Energy (DOE).

6.2.2 Power Plants

Another development in recent years has been in power generation commercially in the United States. This is an issue of concern and interest for three reasons: retirements, replacements, and new plants. The first issue, retirements, is a remnant of the history of the nuclear industry. In the 1950's and 60's large numbers of graduates filled the job market. Those who were 25 years old then will be hitting 65 within the next 5 to

10 years. The job market is expected to open because of retirements, and replacements will be needed.

Replacements will also be needed for those that get promoted, change careers, or some other reason leave the job market. There are no new plants being built, but that does not mean that no new nuclear engineers are needed.

If new plants are ever built, or other research facilities, there must be a number of nuclear engineers in the market in order to fill new openings. And with the Bush Administration in power, the nuclear industry might once again begin a growth period.

6.2.3 Propulsion and Fuel Cells

The energy released in nuclear decay is also utilized in many other power producing applications. Space probes need a constant power source, and because radioactivity is unaffected by temperature, gravity, and acceleration, atomic power sources are often used to power space probes.

Also powered by the same mechanism as space probes, are pacemakers. The advantage of a so-called 'nuclear battery' is that it lasts longer then conventional batteries, and thus would make surgeries for power cell replacements less often for the patient. This use of converting decaying nuclei into thermal and then electrical energy has thousands of uses, and with more work in the field more of the benefits can be realized.

6.3 Research

Current research involving nuclear science provides with an insight to the uses of nuclear science in the near future. There are constantly new uses for nuclear science being studied all the time, and these uses apply to a variety of fields and disciplines. The field that a student enters after attending a university is advanced since the student entered school, so universities must be able to offer programs that keep up to date with current trends and can suitably prepare students for their career field.

The two most prominent places where research is taking places are at national research laboratories and at university nuclear science programs.

6.3.1 National Labs

There are many national laboratories, each carrying out hundreds of experiments. These professional labs are government funded and operated and perform much of the scientific research in the world. The research carried out at the labs provides information on the role nuclear science will play in the future.

One of the most prominent applications of nuclear science being researches at numerous laboratories is the investigation of the quark-gluon plasma (QGP). Quarks and gluons are the particles that make up nuclear matter (protons and neutrons…). The development and study of QGP will provide an idea of the nature of the universe before the big bang, before the creation of nuclear particles. The QGP will give us a better understanding of matter itself, how it was made, the nature of its properties and the forces that govern our physical world.

Of course fusion is being researched worldwide. Different methods using magnetic fields or inertial lasers are being studied and developed with hopes of fusion becoming a viable source of energy in the future. There is a lot of research on the effect of fusion on materials and the nature of the reaction itself. Also new fusion reactor facilities are being built at multiple laboratories to better analyze the process.

Many labs are also developing computer algorithms for computing dose information for radiation therapy. Utilizing the 3D Monte-Carlo technique, researchers are computing how much radiation is absorbed in different parts of the body. This will lead to more effective treatment planning for physicians.

Some other research project taking place at national labs are neutron and x-ray diffraction for investigating the structure and dynamics of chemicals, NASA's radiobiological study of the effects and protection from harsh space radiation, fragment mass analyzers which separate reaction products from the heavy ion beam, the examination of distant stars (which are giant nuclear reactors) and galaxies, the production of tritium and other elements to sustain nuclear stockpiles, and even using neutron activation analysis to examine sculptures and determine their age, the region they were from, and even the stone source they may have originated from.

The nuclear science programs of universities provide an excellent overview of current and upcoming uses of nuclear technology. Not only is the next generation of nuclear scientists learning at these schools, but also a great deal of the most innovative and impacting research is being carried out there. The type of research being performed at universities provides a great deal of information about what the technology is currently being used for and what it will be able to be used for in the near future.

6.3.2 Universities

There are nuclear science programs at schools of all types and all sizes, and it is important to look at the research interests of different universities. Large universities with large nuclear science programs (such as MIT, Ohio State, NCSU…) are often well funded and able to carry out very advanced research in a number of areas, as a result large schools often provide a good indication of where nuclear science is headed. Smaller schools usually don't have the same resources, so they usually concentrate their assets on only a few projects that they think are of the most significance in the present industry, so we can see what these schools think are the most important areas of interest in the field from their research projects.

Of course since WPI is a middle-sized college, it is very important to look at what other middle-sized colleges are doing with nuclear engineering. WPI needs to stay abreast of its competitors. If schools comparable to WPI are producing successful nuclear scientists and taking part in important and lucrative research, it would be in WPI's best interest to also be involved with nuclear science. If not, WPI may lose potential students and potential professionals to other schools. Looking at the nuclear science programs of universities shows the application of nuclear science for many important uses in many fields.

Schools with nuclear engineering programs of all sizes are investigating nuclear fusion. Right now schools like RPI, Cornell, and McMaster are involved in research to model interactions during fusion. Using computers to simulate the fusion process will help find solutions to mitigate the impact of the high heat loads and particle fluxes which severely limit the lifetime of mechanical components. Also, a computer model will help assess types of off normal events that might occur and gauge the frequency and impact of these events with regard to public safety.

Nuclear fusion is already looking to be a promising source of inexpensive energy. The potential fuel supply for fusion is significantly larger than the uranium supply for fission. Also the byproducts associated with nuclear fission are not produced with fusion, which will help alleviate the problem of waste disposal, and also no materials useful for making bombs are produced. As we learn more about the reactions we can optimize the energy production while decreasing any public/environmental dangers. Energy production is one of the largest industries, and as we inevitably move away from fossil fuels it will be important to have alternative energy sources available. Fusion research will undoubtedly have far reaching impact in the near future.

Another large research area is the use of nuclear science for medical imaging, such as tomography and radiography. This research is mostly taking place in medium and large sized schools that also have a prominent bio-med program (such as MIT, NCSU, RPI, McMaster…). Recently research in schools has included creating improved three-dimensional simulations of radiation transport and interactions with the human body, the development of techniques to detect concentrations in organs, and finding effective nuclear doses for patients. These imaging techniques will provide insight into the workings of the human body, as well as new and improved methods of treatment using nuclear medicine.

One of the most prominent applications of nuclear medicine being studied right now at colleges is boron-neutron capture therapy, which was discussed earlier. This is still pretty innovative research, and is therefore mostly pursued at larger schools. Boron neutron capture therapy is an old idea, but it has been getting more attention lately for a few reasons. First is the development of epithermal neutrons that can better penetrate human tissue. Also there are new methods of measuring boron concentration levels in tissue using imaging and other non-invasive techniques. There are also Monte Carlo based dosage calculation algorithms available; these allow the accurate determination of dose in tissues containing boron. With these factors boron-neutron capture therapy is looking to be an important mechanism for battling cancer in the near future.

Neutron activation analysis is another popular research topic at medium sized universities. Since is non-destructive and can analyze a sample of any form (solid, liquid, or gas), neutron activation analysis has uses in many fields. It can be used in medicine to detect concentrations in internal organs, it can be used in geology and anthropology for rock analyses and elemental 'fingerprinting.' In chemistry and biology it can provide elemental analyses, and it can be used to detect elements for environmental scientists. Further development of neutron activation analyses will benefit many fields.

6.4 Other Uses

Nuclear science is facilitating some of the most exciting and advanced research in all areas of science in both universities and professional laboratories. From theoretical physics to medicine, chemistry to materials engineering, even recreating art history. Knowledge of nuclear science plays an important role in many fields and will continue to be so in the future.

6.4.1 Food Irradiation

Irradiation is the use of ionizing radiation or ionizing energy to kill bacteria. The radiation is all high energy, short wavelength. Typical sources are cobalt or cesium ions, electron accelerators, or x-rays. Irradiation is used extensively to treat food products, as well as medical supplies, cosmetics, joint implants, and food packaging.

Irradiation can help reduce the loss of crops due to harmful insects and microbes without the use of chemical pesticides. It also reduces the amount of food-borne illnesses. Opponents of irradiation fear that there may be side effects from irradiation, claiming it increases chances for cancer and liver damage. Another issue with irradiation is the depletion of vitamins and nutrients resulting from the irradiation process. While there is a loss of some vitamins and minerals it is no more than the loss of vitamins and minerals resulting from cooking the food.

While the negative impact of irradiation is highly debatable (many of the issues found were based on studies done in the 1950's, and there are many studies with contradictory results about any side effects from irradiation), the benefits of treating products with irradiation are clear. It is arguably the best method for destroying harmful microbes and insects. Certainly advancing nuclear science will provide even better methods for treating products, and there is also a need for persons with knowledge of nuclear science to perform in depth studies about the process and possible side effects.

6.4.2 Waste Disposal and Pollution Control

One of the largest issues regarding nuclear power and nuclear science is the hazardous nuclear waste that is the bi-product of nuclear reactions. All the nuclear power plants together have the capacity to store about 60,000 metric tons of nuclear waste in their facilities. It is predicted that in thirty years there will be upwards of 85,000 metric tons of nuclear waste. This is a big problem for the nuclear industry, and there is a continual need for scientists and engineers to develop methods to dispose of the waste.

Presently the most promising prospect is to construct a centralized mined underground repository for spent fuel. The site proposed for this project is inside Yucca Mountain, located in a remote desert area in Nevada. The fuel would be stored at least 1000ft. below the surface in an unsaturated zone (above the water level). This way no water will be contaminated. Also the waste will be deep enough underground to protect us at the surface from in case of any accidents, and vice-versa, to protect the waste from us.

There is a lot of research involved in planning a project of this nature. The geological and hydrological conditions of the mountain need to be examined to see if it is suitable to hold radioactive products. Also research to find optimum containment barriers is taking place. The barriers need to be thick, resistant against corrosion, and extremely long lasting. Transportation of the fuel is another issue. Developing large capacity shielded casks to safely move large amounts of waste from nuclear plants to the repository is essential.

There does seem to be a solution to containing the nuclear waste from fission reactors, but before it can be realized there has to be a lot of work done by experts from many fields, geology, materials science, radiology, environmental science, and all need to have a sound understanding of nuclear science and the effects of radiation.

One of the greatest advantages of nuclear power is that it is the lowest emitter of harmful greenhouse gases of any energy source. Greenhouse gases, mainly CO_2 sulfur dioxide and nitrogen oxides, collect in the atmosphere and trap heat from the sun, reradiating the light and heating the planet. The burning of fossil fuels accounts for more than half of the human-induced increase in greenhouse gases, electricity production accounting for half of that amount (see figure 1). Nuclear plants don't directly emit any greenhouse gases. In the 1970's there was an oil shortage, during this time France built many nuclear power plants as an alternative source of energy, and now 78% of France's energy is from nuclear power. As a result they have a $4 billion a year industry in exporting energy to neighbors, cutting the cost of electricity significantly, and their CO_2 production is half of neighboring countries.

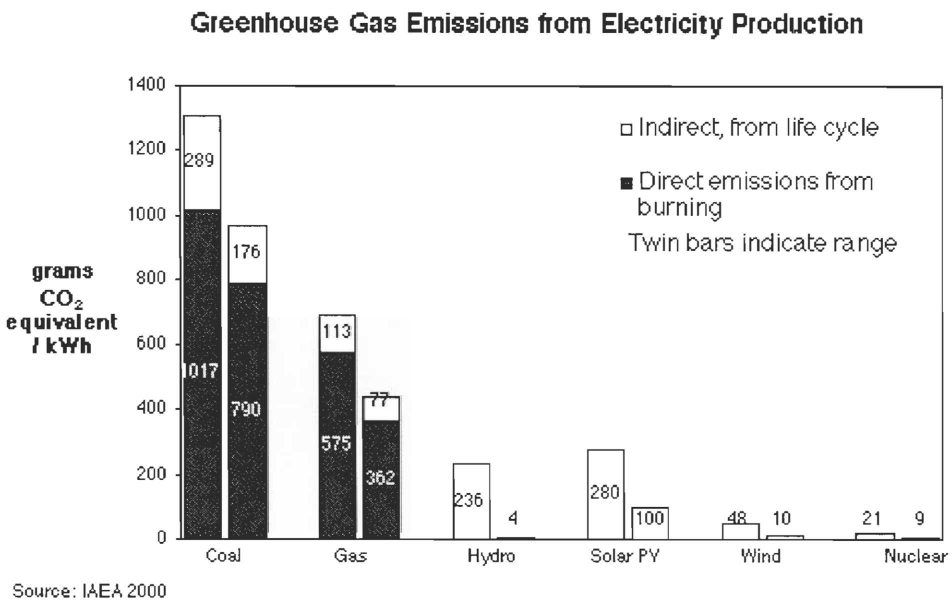


figure 1

It is clear that nuclear power has a lot to offer as opposed to other means of energy production. It is inexpensive and better for the environment. With further study of nuclear science and energy production there will be more efficient reactors producing more electricity while using less energy and producing less waste. There is a great potential in the future of nuclear power that everyone can benefit from.

7. Future Uses and Industry Outlook

> "According to a recent report by the Dept. of Energy, recent graduates and graduates of nuclear engineering programs have outstanding job potential... the expected salary range for engineers with nuclear backgrounds has been consistently higher than other types of engineers."
>
> *~Kansas State Mechanical Engineering Nuclear Option Home Page*

In order to be successful, WPI must offer a program that provides sufficient information relevant to the present and future applications of the engineering field. Usually an undergraduate wishing to pursue a degree in nuclear science will either work for a corporation or continue on to graduate school. Since we are proposing a nuclear science minor, we need to find out what corporations and universities want to see on the transcript of someone who did not major in nuclear science. We also want to look at the nuclear science programs of other schools to see what courses they offer to get a feel of what an average nuclear science student is learning. This directly reflects what a university feels a student entering the nuclear industry should know.

We have seen that Nuclear Technology, despite the change from power to other applications, *has* maintained a strong showing in the areas of science and marketability. Everything from the electricity that powers electric stoves, to the Teflon that is put onto cooking pans, to the grain grown to make bread, to the meat and dairy products eaten everyday: All have been benefited by the atom. But what is the future of this industry?

While a strong past is good, a strong future is what holds the key to establishing a minor program in the radiological sciences.

7.1 Power

Despite little public backing and strong opposition by many environmental groups, the Nuclear Power industry is showing signs of new growth. Plants are being re-licensed and some are increasing generating output. Old Plants are being bought and made profitable again by Utilities. There is even the possibility of a new modular unit being built at an existing plant, which would be the first true growth in our nuclear generation since the 1970's.

7.1.1 Current Situation

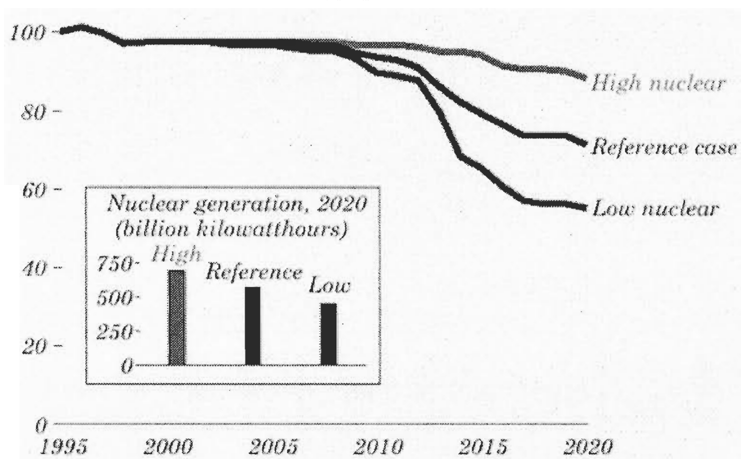
Nuclear Engineering at power plants is nearing a crisis. There are 496 nuclear power plants (30+ MW (e)) in the world either operating or in the process of being built. 107 of these are in the United States. (Numbers as of March 200 from *Nuclear News*) These plants produce 20% of the nations power. These plants are expected to be around for quite a while however, with many in the past 5 years extending their licenses and more applying for extensions. The end of the 1990's and the beginning of the new millennium have been good times for the existing plants in the United States. In 1999, according to the Institute of Nuclear Power Operations for the World Association of Nuclear Operators, a United States record of 725 billion Kilowatt-hours of electricity were produced at US Nuclear Power Plants. The safety of power plants was also great in the same year – and average of 0.34 accidents pew 200,000 man-hours of work, compared to 2.9 per 200,000 in the manufacturing sector, according to the US Bureau of Labor Statistics.

The size of the nuclear power industry is thus still large and will be for years to come. Many retirements are expected in the next years as previously explained, and the Bureau of Labor Statistics (BLS) has estimated that the Nuclear Engineering Field will grow slightly over the next years. BLS also states that the median annual earnings of nuclear engineers were $71,310 in 1998. The national Association of Colleges and Employers in their fall of 2000 Salary Survey also put nuclear engineers in the $70,000/year range. This is a very good salary, and shows that there is demand for nuclear engineers in the US job market. Nuclear Engineers are defined as engineers who work on power plants, instrumentation and control systems, or other work related to technology and power production.

7.1.2 Market Outlook

The Department of Energy's Annual Energy Outlook for 2001 looked in detail at the future of the Nuclear Industry. The study identified two scenarios, a 'high nuclear' and a 'low nuclear', estimating the highest and lowest possible futures in terms of nuclear power. There is ambiguity because of the re-licensing prospect many plants are considering. In the expected case (most probable future) only one unit (individual reactor at a plant) is expected to shut down prematurely, while at least 27 are expected to continue operating after their original 40-yeaer license expires. In 2000, 2 extensions have been approved by the NRC, with 3 under review and more than 17 plant owners having announced their intensions to apply for an extension. The chart seen on this page shows the DOE's estimates for giga-watts of production in the scenarios described above. As you can see, there will not be any significant decline in the industry until 2013, and, as the high nuclear case shows, there is a chance that the industry will be around 90% of what it is now in 20 years. These figures are assuming no new plants being built, which, with the new Administration focusing on the current energy crisis and the NRC having approved a new plant design as "safe and ready to be constructed", may not be the case at all. There has been large investment in the nuclear plants in the past few years, and new energy and resources are being put in to ensure that our plants remain for as long as possible. The Department of Energy has said that nuclear power is one possible answer to the growing Carbon Dioxide emissions problems associated with global warming and the greenhouse effect. In the high nuclear scenario, 14 Giga-watts of new production will not be needed, and, because this shortcoming would be filled with fossil-fuel plants most likely, a total of 16 million metric tons carbon equivalent of

Figure 79. Projected operable nuclear capacity in three cases, 1995-2020 (gigawatts)



History: Energy Information Administration, *Annual Energy Review 1999*, DOE/EIA-0384(99) (Washington, DC, July 2000). **Projections:** Table F6.

emissions will NOT be put into the atmosphere. Not only is nuclear power better for the atmosphere, it is also cheaper. In 1999 nuclear power cost an average of 1.83 cents per kilowatt hour, while coal was 2.07 cents, and oil and natural gas both over 3 cents per kilowatt hour.

The DOE has said that while enrolment in nuclear programs has dropped, the demand for jobs has grown. Starting salaries for engineers with nuclear backgrounds have been consistently higher than other types of engineers. This is where the strength of a multidisciplinary minor comes in. Not only is nuclear good for nuclear engineers, but for MANY occupations a background in nuclear can help.

7.2 Medical And Other Fields

The health benefit from nuclear science is amazing. Dental X-rays, MRIs, PET Scans, Nuclear Imaging, radionuclides, and many other procedures are all in the field of nuclear technology. These have already been shown to be cutting edge technology in Section 6.2. These procedures are deemed safe and are performed all the time across the country. The people whom perform these procedures must have training in nuclear science and engineering. The job market for medical technicians with a nuclear background is strong.

7.2.1 Radiological Technicians

Radiologic technologists held about 162,000 jobs in 1998, with another 14,000 jobs in nuclear medicine, according to the BLS. BLS estimates that a more disciplinary worker will be sough after more so than others. “Radiologic technologists who are educated and credentialed in more than one type of imaging technology, such as radiography and ultrasonography or nuclear medicine, will have better employment opportunities as employers look for new ways to control costs,” said the BLS in its Job Outlook for Radiologic Technologists.

7.2.2 Nuclear Medicine

Nuclear Medicine is a huge field, and it is growing. The Society of Nuclear Medicine reports that there are nearly 100 different nuclear imaging procedures available today, and estimates that between 10-12 million Nuclear Medicine imaging and therapeutic procedures are done in the United States each year.

SNM reports also that over 70% of its members work with these techniques in a hospital environment, and that nearly 50% of them listed imaging as their primary task. The median salary is listed around $45,000/year. It is taken for granted how often we utilize radiological procedures, whether it be medical imaging such as X-rays at the dentist of ER, or an MRI or PET scan, or Radiation Therapy for cancer, overactive thyroid, or other uses even, such as airport security, smoke detectors, and power plants. These people who perform these procedures are very important in today’s society.

Nuclear Medical Technicians are involved in nuclear procedures, such as radiopharmaceutical application and nuclear imaging. The BLS defines the types of classes that one must take to become a Nuclear Medicine Technologist as those which cover physical sciences, the biological effects of radiation exposure, radiation protection and procedures, the use of radio-pharmaceuticals, imaging techniques, and computer applications. The job market for NMT through 2008 is expected to grow about 10-20%. The 1998 average salary was $39,610/year.

Radiological Technicians are different in the fact that they deal with all types of radiation, including X-rays and magnetic radiation. Radiological technicians will see a growth of around 20% through 2008 as well. However, the mean salary was lower, coming to around $33,000/year.

Higher degrees will yield better paying jobs, mostly out of the technician role and into the research and development roles. Research into imaging techniques needs high education in Nuclear Engineering/Radiological Sciences and Biology/Biotechnology and maybe Biomedical Engineering. Thus, to be on the cutting edge of technology, students must start with a multidisciplinary education, learning the biological side of the field as well as nuclear principles such as ionizing radiation, nuclear decays, and radiation transport. Reactor physics is NOT needed to go into this area. As with most of these medical uses (perhaps apart from BNCT, which needs reactors to produce thermal neutrons for the therapy), radiological principles, not nuclear principles, are needed. A successful program would allow radiological learning apart from nuclear and reactor physics courses. This would allow two general course paths to be taken, one focusing on radiation, one on fission. Currently the program only offers the latter.

7.3 Academic Institutions

After being asked what background they look for in non-nuclear science majors applying to their graduate program for nuclear science, almost all of the numerous universities polled said that most engineering or physical science majors would be able to study nuclear science at the graduate level. Some of the courses that would better prepare a student are advanced calculus, thermodynamics, and atomic and nuclear physics for nuclear engineering programs. More specifically for fission engineering: thermo-hydraulics and nuclear physics are recommended, for fusion engineering: electromagnetic theory and nuclear physics are recommended. For nuclear materials engineering schools want students with experience in material properties and radiation effects. Similarly for nuclear medicine and health physics related fields most schools recommend radiation transport and effects, nuclear physics, and biology classes for undergraduates.

Some universities offering a minor in nuclear science require students to take an introductory nuclear physics class and a biophysics/radiation class, and then offer a selection of other nuclear related classes mostly based around (but not restricted to) reactor physics, health physics and biophysics, nuclear energy, and nuclear safety. This format exposes students to different aspects of nuclear science, and it is always beneficial to get multiple perspectives on any subject.

8. A Program Proposal

> "The WPI curriculum, accordingly, has been reshaped numerous times, but it has remained true to its original mission of fusing academic inquiry with social needs, of blending abstraction with immediacy, of linking new knowledge to applications."
>
> *~From 'The Goal Of WPI', Undergraduate Catalog, 2001*

8.1 A Minor at WPI

There is a need for a minor in nuclear and radiological technology. It has been shown that nuclear science applies to many fields, including physics, civil engineering, biology and biotechnology, chemistry and chemical engineering, and mechanical engineering. The current program and program of past years was considered a major and dealt solely with nuclear power issues. But, as has been shown, the field has shifted and now is incorporated into many different fields. Based on the data available, it is suggested that WPI work to set up a minor in Radiological and Nuclear Engineering, to be applied to many different majors depending on the circumstances. A minor could be worked such that it fits the WPI definition and requirements for a minor, can be made so that students of many majors can complete and benefit from such a minor, and be made with a minimal addition of courses to the curriculum. There is substantial overlap with current courses in many departments, and this many current courses can count towards a minor.

WPI defines the goal of the university as "to create and convey the latest science and engineering knowledge in ways that would be most useful to the society from which its students came." The minor at WPI is a set of courses that are related in some way such that the information gained is in addition to but separate from the major. A Nuclear minor fits this definition perfectly – it is a tool of biology, chemistry, and physics, but it itself is separate from these fields. A minor in Radiological and Nuclear Engineering and Sciences would focus on the relationships between a students primary areas of study and the field of NE, so as to teach the students how to utilize the power nf the atom to the advantage of their own field of study.

The requirements for a minor include 2 units of work, 1/3 of which must be a capstone experience, which signifies the completion of the minor. Up to one unit of these two units may be double counted… in other words, a class that counts towards another degree requirement may also count towards the minor, as long as the content of the course can apply towards both subjects. Minors must be proven to "achieve an educational goal beyond those apparent or implicit in the regular degree requirements." This minor would signify that not only is a student proficient in their own field of study, but they can additionally work with radiological sciences *as they apply to their major.* This is the key of the minor proposal – tailoring the program so that it is applicable to each and every student and his/her major. This can be done by offering a few courses which encompass the basics of nuclear sciences and radiation, giving students the foundation to build on their specific areas. This additional study can be done with a few new course offerings and also through courses already offered at WPI, such as Biomedical Imaging techniques, nuclear physics, etc.

8.2 Core Nuclear Courses

The establishment of a program will of course need a certain number of courses pertaining to the subject. Some of these courses will be lower level introductory courses, and others would be higher-level courses.

8.2.1 Introductory Courses

The core nuclear courses would be courses that could count as either NE (Nuclear Engineering) or ES (Engineering Sciences) courses, and would consist of three basic introductory courses. The first would be Introduction to Nuclear Science and Engineering, which would give the basic knowledge of radiation, nuclear decays, and the basics of nuclear engineering and applications. The second course in the Introductory sequence would cover health physics and get into the applications of the technology learned in the first course. The title could be Radiological Engineering: Nuclear Applications and Radiation Protection. It would cover production and uses of radioisotopes, power generation, and radiation measurement uses (medical imaging, shielding, manufacturing processes, etc.)

8.2.2 Upper Level Courses

Upper level courses that would need to be added to the curriculum would include 2 courses in the NE department, including Radiation Transport: Attenuation, Effects and Measurements, as well as Nuclear Criticality Theory and Analysis. The first would cover how radiation permeates through mediums, how cells are affected by radiation of different types, how radiation is categorized based on biological effects, and radiation detectors. The second would combine the old Nuclear Reactor Principles and Nuclear Reactor Laboratory courses, giving knowledge of reactor principles and reactor physics through both lecture and lab work. (Note: this course would be dependent on having the WPI Nuclear Reactor Facility open and operational) Additional courses that are aimed at different majors may include a Radiobiology and Nuclear Chemistry course. These advanced courses could be taught by current faculty in their associated departments, thus eliminating the need for additional faculty to be hired.

8.3 Departments with Nuclear Relationships

These courses, along with several courses that already exist here on campus, would comprise the core of the nuclear curriculum. To fulfill the sequence of courses making up the 2 units (6 courses) of work, students would take the two introductory Nuclear Engineering classes, to be followed by courses depending on their major.

8.3.1 Relationships

Relationships exist between nuclear science and nearly every major at WPI. This proposal only deals with a few of the majors. Each has its own unique link to nuclear science, and has a list of courses that would fulfill the program path.

8.3.2 Existing Courses

These majors have courses that already have a certain amount of Nuclear Engineering or Radiological Science topics in them, and thus would be able to count towards the minor's 2 units of coursework.

8.3.2.1 Biology/Biotechnology

The Biology/Biotechnology Department had its own version of a nuclear minor, known as a tech-pack. This involves a cluster of three courses that denote an area of concentration for students pursuing a Biology degree. With the ending of the NE program and classes through the ME Department, the Nuclear Option was dropped. A revival of programs would once again allow students to choose this path, and thus any student wishing to pursue biology and nuclear engineering could do so not through the minor but through this alternate channel.

8.3.2.2 Biomedical Engineering

For biomedical Engineering, the biggest application is under nuclear imaging and nuclear medicine. For these topics to be sufficiently learned, course paths would have to include BE 581, *Medical Imaging Systems*, a course currently offered which deals with nuclear imaging. Also a radiation transport class would allow students to learn how imaging systems work and how radiation travels through different mediums. Also, a radio-biology course would discuss the effects of radiation on cells and both the harmful and beneficial results of such effects.

8.3.2.3 Civil Engineering

Civil Engineers wishing to pursue a nuclear minor would most likely be interested in aspects such as power plant construction, design, waste disposal proposals, and environmental effects. Courses of interest would include possibly a radioactive waste management course, as well as radiation transport, GE 2341, *Geology*, Reactor Physics, and CE 3022, *Legal Aspects In Design and Construction.*

8.3.2.4 Physics

Physics has many courses which would be beneficial to someone interested in nuclear science. PH 3503, *Nuclear Physics*, as well as PH 2651, *Intermediate Physics Laboratory* have nuclear content. Quantum Mechanics courses have a certain amount of nuclear information as well. In addition, a Nuclear Criticality Theory course would apply to physics majors.

8.3.2.5 Mechanical Engineering

The Mechanical Engineering Program would basically remain as it once was, only the distinction would be a minor instead of a concentration. Courses such as heat transfer, fluid mechanics, compressible flow, environmental issues and analysis, and all of the proposed Nuclear Courses could apply.

8.3.3 Capstone

The capstone project could, as is done for many majors, be one of the upper level courses. Appendix B contains a pamphlet with specifics about the proposal and course lists/paths.

9. Conclusions

Although the power-oriented nuclear program that WPI has had in the past was becoming obsolete, the removal of the program alone is an imprudent solution. Nuclear Science and technology represents a major part of today's cutting edge sciences and is at the heart of many scientific and technological developments.

Current trends in the field of nuclear science illustrate that it is a major part of today's technological society. Nuclear science has a profound influence on nearly all branches of science and engineering. It continually improves the quality of life and is constantly shown to better society. For a technological oriented school to remain at the forefront of science, it must have a nuclear program. A nuclear major is not where the technology lies today. Instead, multidisciplinary uses for the power of the atom are becoming the mainstay of what defines nuclear science and its uses. Its medicinal and environmental applications are continually raising human standards for living. Nuclear science is an incredibly valuable resource to chemists, chemical engineers and biologists. And of course nuclear energy is always striving to become more efficient and safety conscious.

In order to keep with the changing times WPI must institute a nuclear minor program, allowing interested students to pursue not only their major field of study but also incorporate the associated areas of nuclear technology which will enhance the education that they receive, and allow them to successfully work in a nuclear related field.

A familiarity with nuclear science will provide students from a variety of disciplines with the opportunity to work in many important groundbreaking technological fields. Students attending an esteemed technical university should be given this opportunity, especially with the future prospects of nuclear science.

The curriculum for the minor in nuclear science must provide students with courses that will adequately meet the expectations of whichever field that student is pursuing as well as lay the foundation of working with nuclear science.

The actual implementation of the program is another issue. Monetary issues, political issues, and the future of the WPI Nuclear Reactor were not considered in this project. Only the need for such a program was analyzed, not the feasibility. It has been clearly shown that nuclear science is a major part of technology and will continue to be. Schools have been successful in adapting nuclear science as a minor, which can be applied to other majors. WPI and its students stand to benefit from the implementation of a nuclear science minor.

10. Source List

Farncombe, Troy and Anna Celler. (28 October 1998) "Medical Imaging Research Group, Vancouver, B.C." Medical Imaging Research Group, Vancouver Hospital and Health Sciences. Retrieved from the World Wide Web: [http://www.physics.ubc.ca/~mirg/] on (7 April 2001).

Walker, J. Samuel. <u>A Short History of Nuclear Regulation</u>. Washington D.C.: NRC, 2000. [http://www.nrc.gov/SECY/smj/][shortis.htm].

Perez, Pedro ed. (22 February 2000) "TRTR." National Organization of Research and Training Reactors. [http://www.trtr.org/Links/][TRTR_February.html] .

(31 May 2000) "NE Program Main Page." Nuclear Engineering Program, WPI NRF. [http://www.wpi.edu/Academics/Depts/ME/Nuclear/Nuclear_Program/NRF/] [nrf.html].

(16 February 2001) "Navy Fact File: Aircraft Carriers." Aircraft Carriers – CV,CVN. [http://www.chinfo.navy.mil/navpalib/factfile/ships/][ship-cv.html]

(20 October 2000) "RSNA 200 Exhibitor Prospectus: 1999 Attendance profile." Exhibitor Prospectus. [http://www.rsna.org/rsna2000/exhibitinfo/prospectus/] [attendanceprofile.html].

"Nuclear." Nuclear Engineering. [http://www.rpi.edu/dept/env-energy-eng/public_html/Academic_Programs/Nuclear/] [nuclear.html] (17 February 2001).

"MIT Nuclear Engineering Department." MIT Department of Nuclear Engineering. [http://web.mit.edu/ned/www/] (17 February 2001).

(21 February 2000) "Home Page of The Ward Center For Nuclear Sciences @ Cornell Univ." The Ward Center For Nuclear Sciences. [http://www.osp.cornell.edu/VPR/Ward/][WCNS.html] (19 February 2001).

(1997) "Introduction to BNCT!" Boron Neutron Capture Theory, Harvard/MIT. [http://www.bnct.bidmc.Harvard.edu/][Introduction.htm] (7 April 2001).

(6 April 2001) "Science and Technology at Los Alamos National Laboratory." Los Alamos National Laboratory Science and Technology. [http://www.lanl.gov/worldview/][science] (7 April 2001).

(2001) "Argonne Programs" Argonne Research Programs and National Scientific User Facilities. [http://www.anl.gov/OPA/][progs.htm] (7 April 2001).

(20 March 2001) "Research Departments & Divisions" Brookhaven National Laboratories Research Departments & Divisions. [http://www.bnl.gov/bnlweb/][departments.html] (7 April 2001).

(25 March 2001) "Oak Ridge National Laboratory: Science and Technology" Science and Technology. [http://www.ornl.gov/ornlhome/][science_technology.htm] (7 April 2001).

(14 December 2001) "Science Technicians." Occupational Outlook Handbook. [http://stats.bls.gov/oco/][ocos115.htm].

(30 July 2000) "Radiological Technologists." Occupational Outlook Handbook. [http://stats.bls.gov/oco/][ocos105.htm].

(5 January 2001) "Nuclear Medicine Technologists." Occupational Outlook Handbook. [http://stats.bls.gov/oco/][ocos104.htm].

(5 January 2001) "Nuclear Engineers." Occupational Outlook Handbook. [http://stats.bls.gov/oco/][ocos036.htm].

(11 January 2001) "Electric Power generating Plant Operators and Power Distributers and Dispatchers." Occupational Outlook Handbook. [http://stats.bls.gov/oco/] [ocos227.htm].

(June 2000) "NRC: Information Digest 2000 Edition (NUREG 1350, Vol. 12)." Appendix E: U.S. Nuclear Nonpower Reactors from the Division of Planning, Budget and Analysis. [http://www.nrc.gov/NRC/NUREGS/SR1350/V12/] [part15.html], and Appendix I: World list of Nuclear Power Reactors <30+MW(e)> [http://www.nrc.gov/NRC/NUREGS/SR1350/V12/] [part19.html] (31 January 2001).

(23 October 1997) "Career Fields in Nuclear & Radiological Engineering." The Career Fields of Nuclear Engineering, Radiological Engineering & Health Physics. [http://www.me.gatech.edu/me/employment/] [career.fields.html] (31 January 2001).

(1999) "Manpower." Research and Data Technologist Salary/Survey Information done by the Nuclear Medicine Technology Certification Board. [http://www.snm.org/research/] [1999nmtcb.html] (31 January 2001).

"Public Data Query: ee." National Employment, Hours, and Earnings. [http://146.142.4.24/labjava/] [outside.jsp?survey=ee].

"NRE Course Listing." NRE Semester Courses. [http://www.me.gatech.edu/me/semester_conversion/] [nrecourselist.html].

Bajorek, Stephen. "Nuclear Option Page." Mechanical Engineering Nuclear Option. [http://www.mne.ksu.edu/~bajorek/Nuclear_Option/] [no.htm] (31 January 2001).

Griffith, H. Winter, M.D. Compete Guide to Medical Tests. Fisher Books, 1988. [http://www.testuniverse.com/mdx/] [MDX-3117.html].

Lake, James. A. “Looking Towards the Future <presidents column>.” ANS News Jan/Feb 2001.

Tymeson, Mildred M. Two Towers: The Story of Worcester Tech 1865-1965. Worcester: WPI, 1965. [http://www.wpi.edu/Academics/Library/Archives/TwoTowers/] [page197.html].

Hutzler, Mary J et al. Annual Energy Outlook 2001. Washington D.C.: Department of Energy, 2001. [http://www.eia.doe.gov/oiaf/aoe/].

“Fast Facts about Nuclear Medicine.” What Is Nuclear Medicine. [http://www.snm.org/nuclear/] [facts.html].

“AAPM Fact Sheet.” American Association of Physicists in Medicine AAPM Online Fact Sheet. [http://www.aapm.org/org/] [aapm_fact_sheet.html].

2000-2001 Rensselear Catalog. Troy NY: RPI Office of Marketing and Media Relations, 2000.

Srivasta S.C. Criteria for the selection of radionuclides for targeting nuclear antigens for cancer radioimmunotherapy. Cancer Biother. Radiopharm. 11:43-50, 1996.

Coderre, J.A. “Boron Neutron Capture Theory.” In Liebel S, Phillips T (eds) Textbook of Radiation Oncology. Philadelphia: W.B. Saunders Company, 1998, pp.1263-1277.

Martin, R.C., et al. "Neutron Activation Analysis at the Californium User Facility for Neutron Science," vol.2, 1998 pp.442-449 Proc. Am. Nucl. Soc. Radiation Protection and

Shielding Division Top. Conf. on Technologies for the New Century, Nashville, TN, American Nuclear Society, April 1998.

Verghese, Kuruvilla, and John Gilligan., ed. Nuclear Engineering Education Sourcebook. 2000 ed. Raleigh, NC: NCSU 2000.

Flippo, Kirk A, graduate research assistant. Personal communication through the University of Michigan NERS 'Ask A Nuke' program on 6 April 2001.

Jim Muckerheide. Personal communications.

David Adams, Associate Professor of Biology. Personal interview, 6 February 2001.

Christopher H. Sotak, Dept. Head Biotechnology. Personal interview.

Allison F.Corkey, Asst. Director, Career Services. Personal interview, 30 March 2001.

Perez, Pedro B. University Research Reactors: Contributing to the National Scientific and Engineering Infrastructure from 1953 to 2000 and Beyond. Raleigh, NC: 2000.

Taylor, Gegg M. (ed.). "Late News." Nuclear News April 2000 p17.

WPI 2000-2001 Undergraduate Catalog. WPI Office of the Registrar, 2000.

Salary Survey from WPI Career Development Center, provided by A.F. Corkey, Asst. Director of Career Services. "Average Yearly Salary Offers for Winter/Spring/Summer/Fall 2000."

Previous Student Data

Course: NE2001	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	Total Students 88-01	average Students/yr
Total Students	15	7	18	24	12	11	16							103	7.92
ME Students	5	6	8	9	5	6	6							45	3.46
non-MEStudents	10	1	10	15	7	5	10							58	4.46

Course: NE2002	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	Total Students 88-01	average Students/yr
Total Students	8	9	8	11	20	17								73	5.62
ME Students	5	7	7	5	7	9								40	3.08
non-MEStudents	3	2	1	6	13	8								33	2.54

Course: NE2011	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	Total Students 88-01	average Students/yr
Total Students								21	3	3	20			47	3.62
ME Students								7	3	1	7			18	1.38
non-MEStudents								14	0	2	13			29	2.23

Course: NE2012	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	Total Students 88-01	average Students/yr
Total Students								10	10	5		3		28	2.15
ME Students								5	6	2		0		13	1.00
non-MEStudents								5	4	3		3		15	1.15

Course: NE3101	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	Total Students 88-01	average Students/yr
Total Students	4	8	8	7	17	14	14	8	6	1	3			90	6.92
ME Students	3	6	6	5	10	10	9	5	5	1	2			62	4.77
non-MEStudents	1	2	2	2	7	4	5	3	1	0	1			28	2.15

Course: NE3301	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	Total Students 88-01	average Students/yr
Total Students	3	6	5	7	10									31	2.38
ME Students	2	6	4	4	8									24	1.85
non-MEStudents	1	0	1	3	2									7	0.54

Appendix A.

Course: NE3401	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01		
Total Students								4						4	0.31
ME Students								4						4	0.31
non-MEStudents								0						0	0.00

Course: NE4102	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01		
Total Students			10			9	13	3	8		5			48	3.69
ME Students			6			8	7	2	7		5			35	2.69
non-MEStudents			4			1	6	1	1		0			13	1.00

Course: NE4301	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01		
Total Students									7		3			10	0.77
ME Students									6		2			8	0.62
non-MEStudents									1		1			2	0.15
														0	

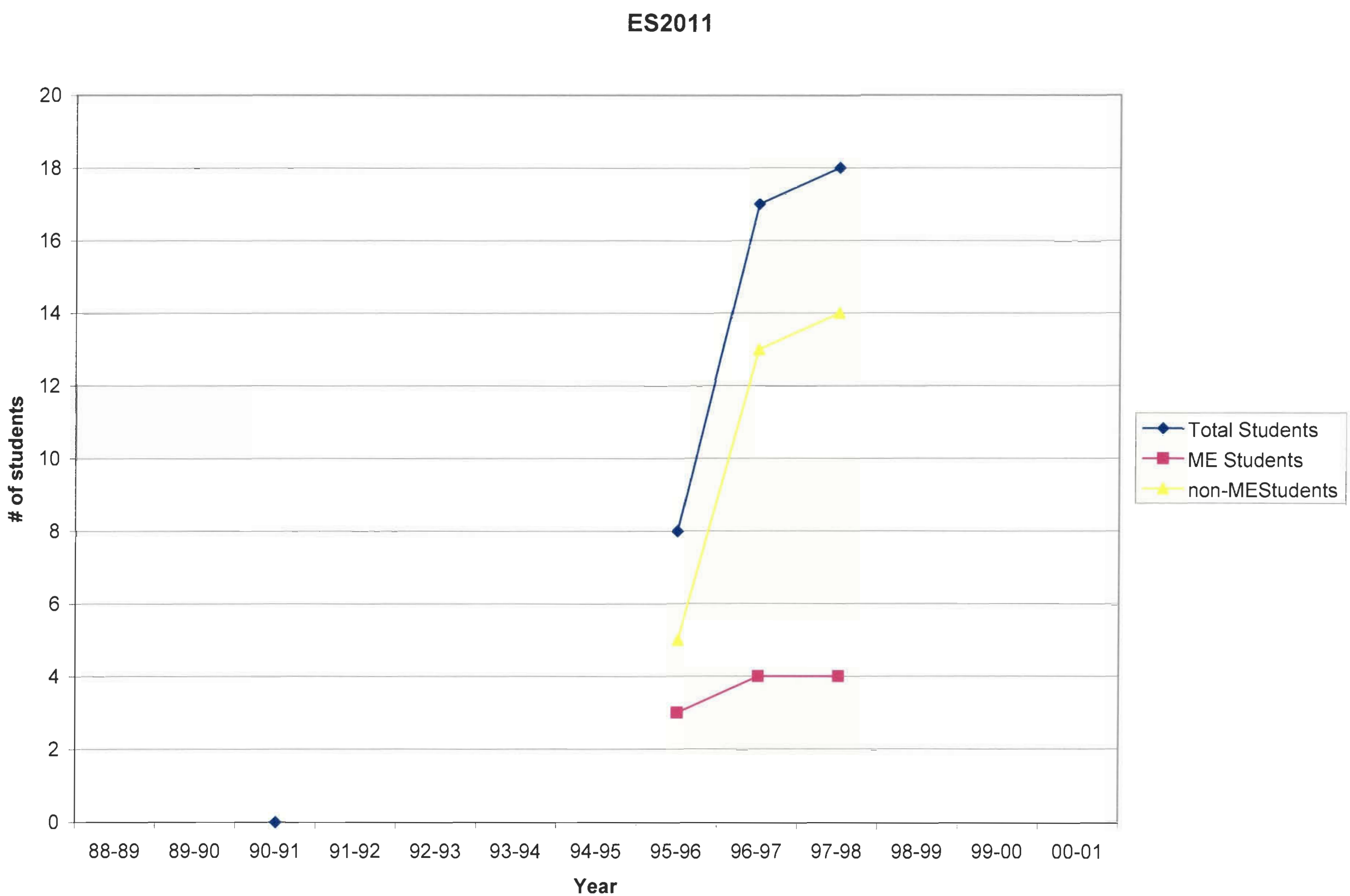
Course: NE4302	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	0	
Total Students								14		2		1		17	1.31
ME Students								9		1		0		10	0.77
non-MEStudents								5		0		1		6	0.46

Course: NE432x	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01		
Total Students						14								14	1.08
ME Students						12								12	0.92
non-MEStudents						2								2	0.15

Course: NE4401	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01		
Total Students			2											2	0.15
ME Students			1											1	0.08
non-MEStudents			1											1	0.08

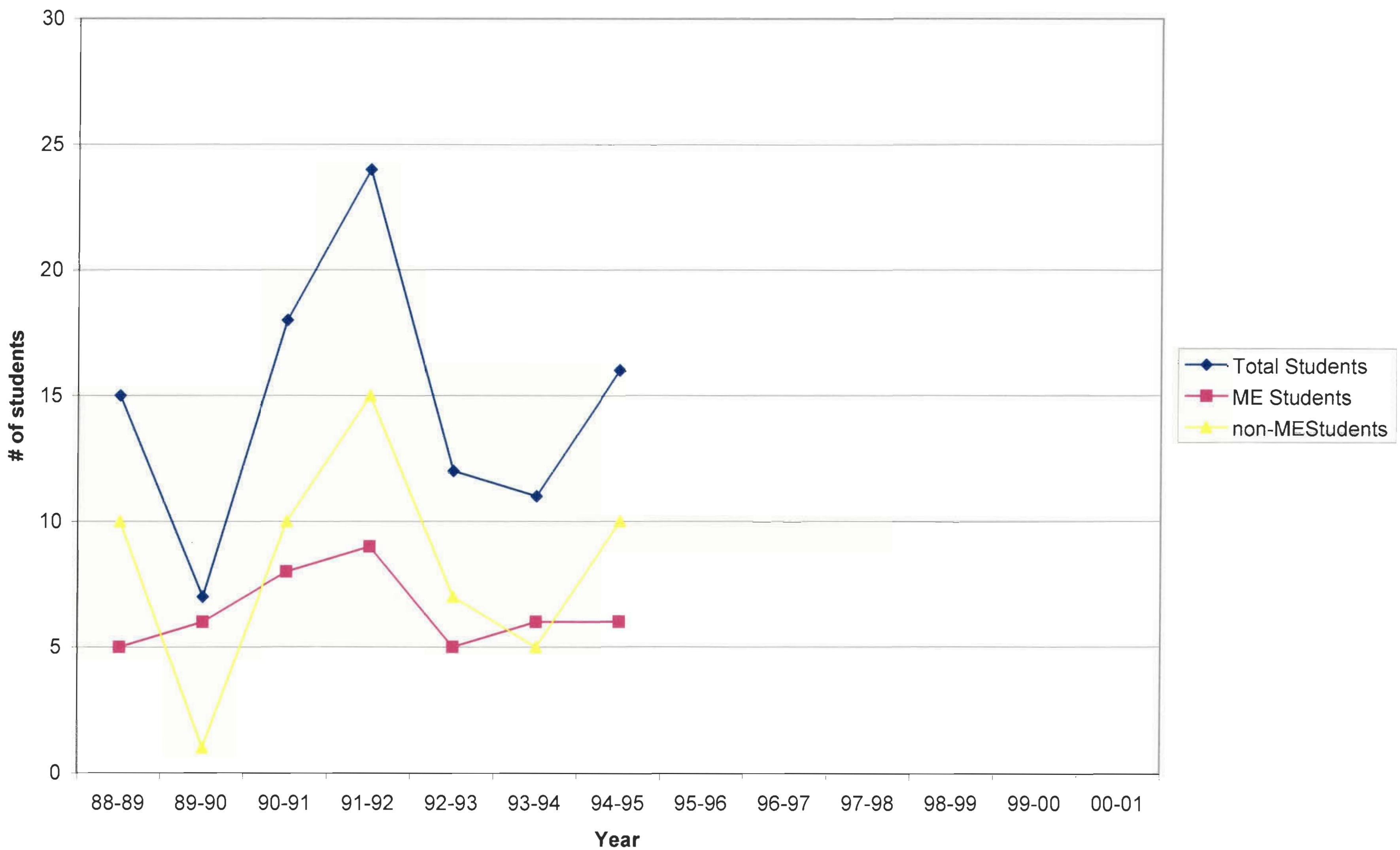
Course: ES2011	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01		
Total Students			0					8	17	18				43	3.31
ME Students								3	4	4				11	0.85
non-MEStudents								5	13	14				32	2.46

	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01		
Lower Level Couse Total	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01		
Total Students	23	16	26	35	32	28	16	39	30	26	20	3	0	294	22.62
ME Students	10	13	15	14	12	15	6	15	13	7	7	0	0	127	9.77
non-MEStudents	13	3	11	21	20	13	10	24	17	19	13	3	0	167	12.85
Upper Level Course Total	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01		
Total Students	7	14	25	14	27	37	27	29	21	3	11	1	0	216	16.62
ME Students	5	12	17	9	18	30	16	20	18	2	9	0	0	156	12.00
non-MEStudents	2	2	8	5	9	7	11	9	3	0	2	1	0	59	4.54
All Courses	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01		
Total Students	30	30	51	49	59	65	43	68	51	29	31	4	0	510	39.23
ME Students	15	25	32	23	30	45	22	35	31	9	16	0	0	283	21.77
non-MEStudents	15	5	19	26	29	20	21	33	20	19	15	4	0	226	17.38

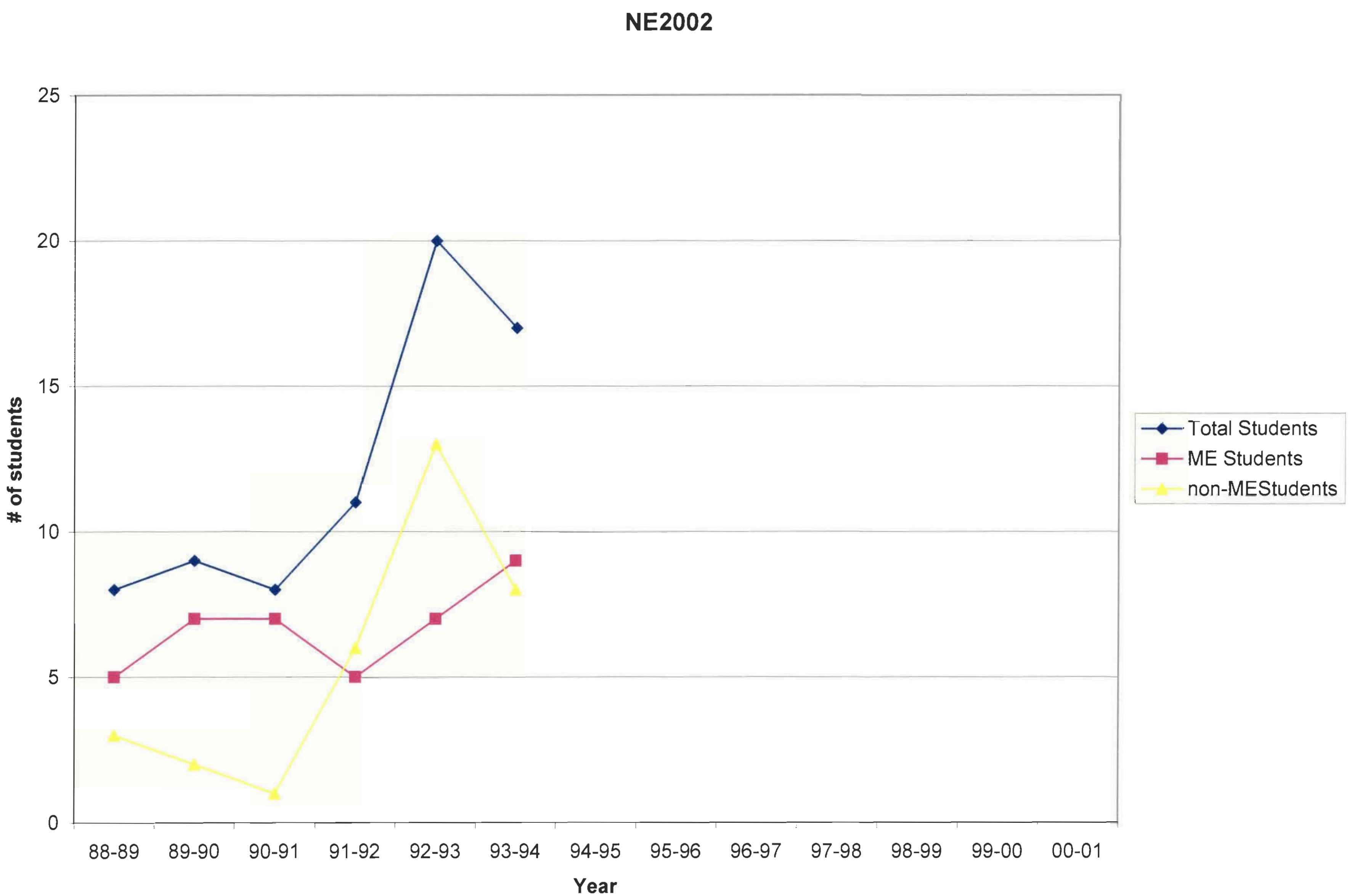


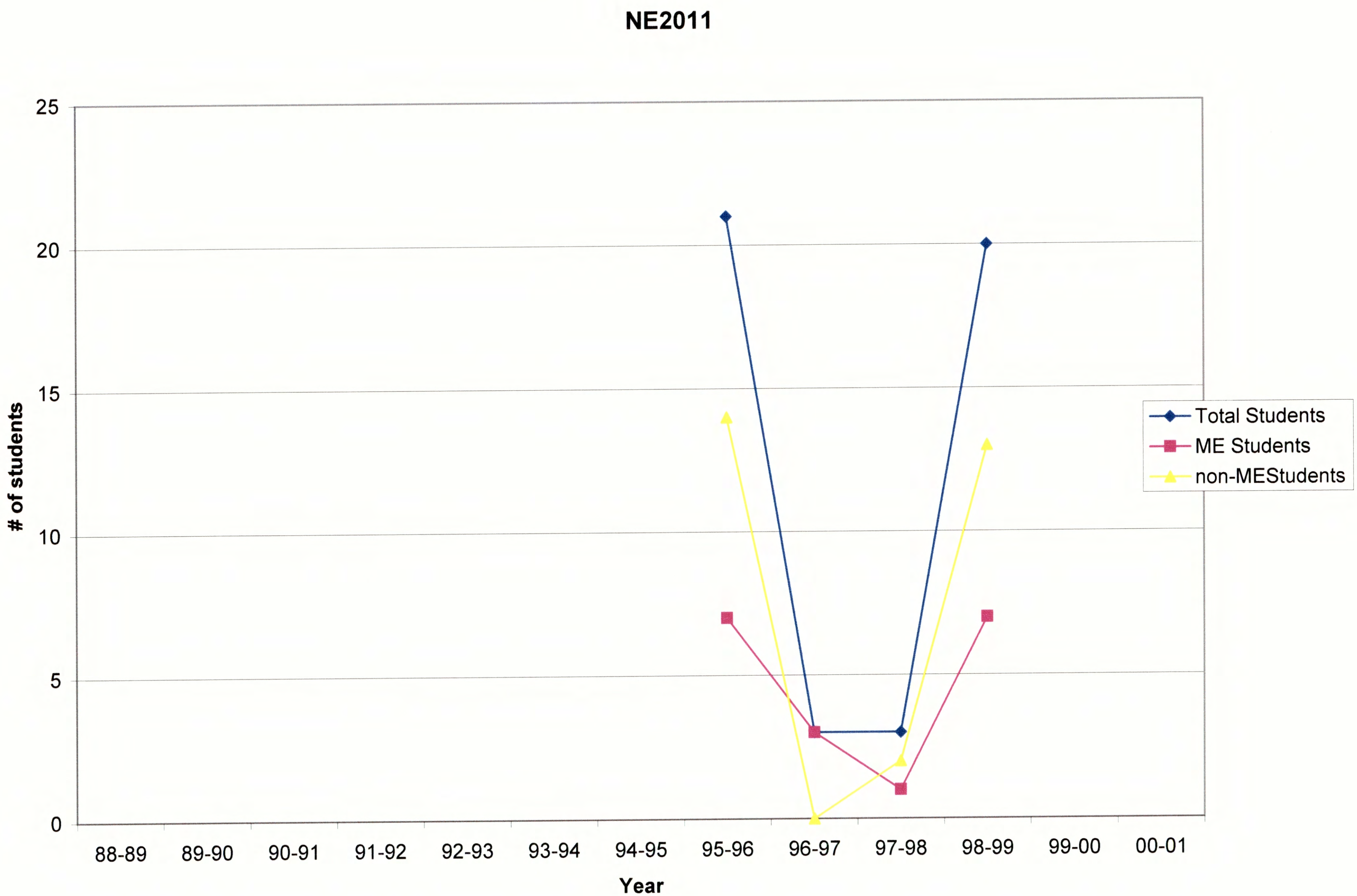
ES2011
# of students
20
18
16
14
12
10
8
6
4
2
0
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents

NE2001

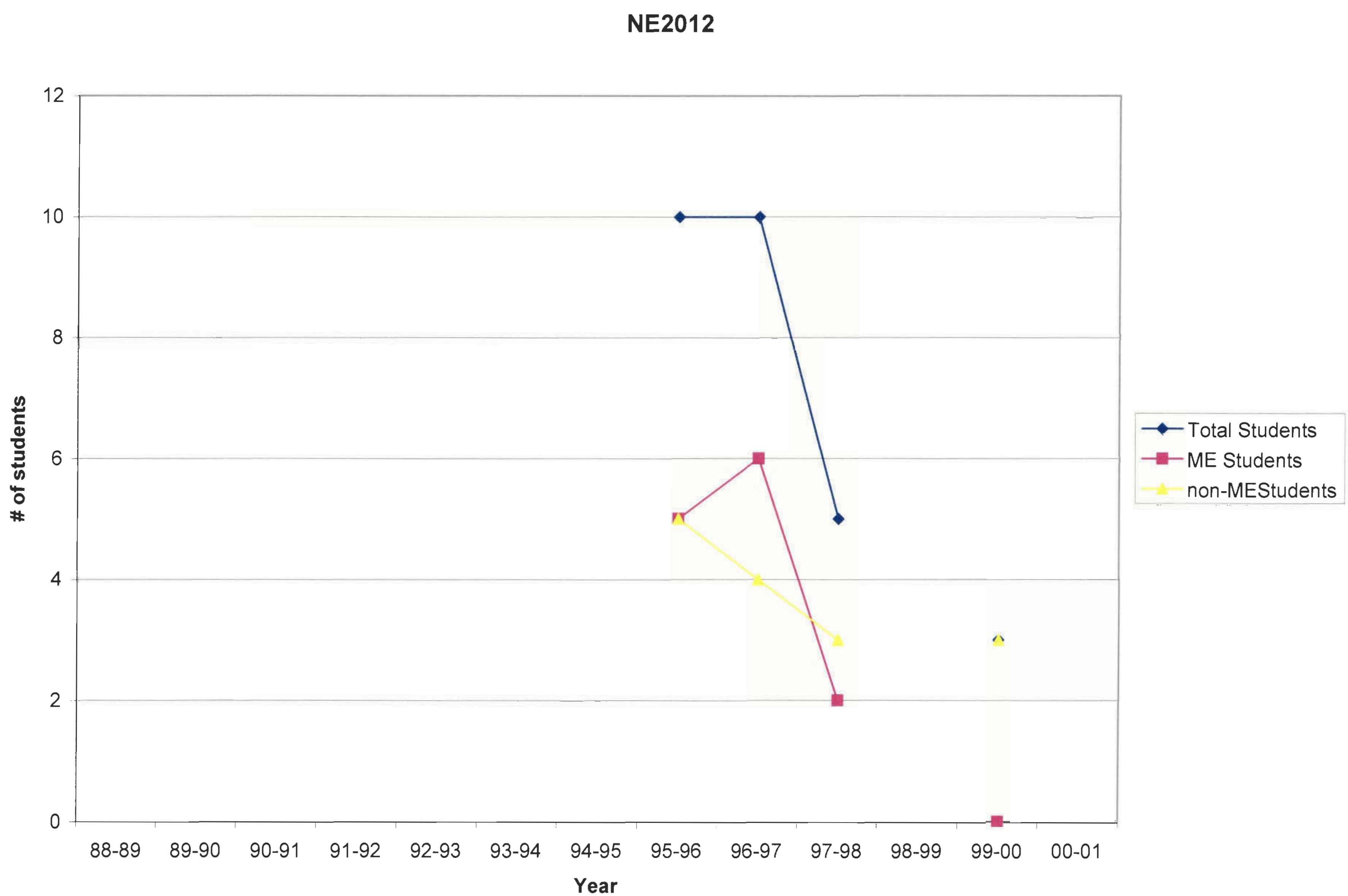


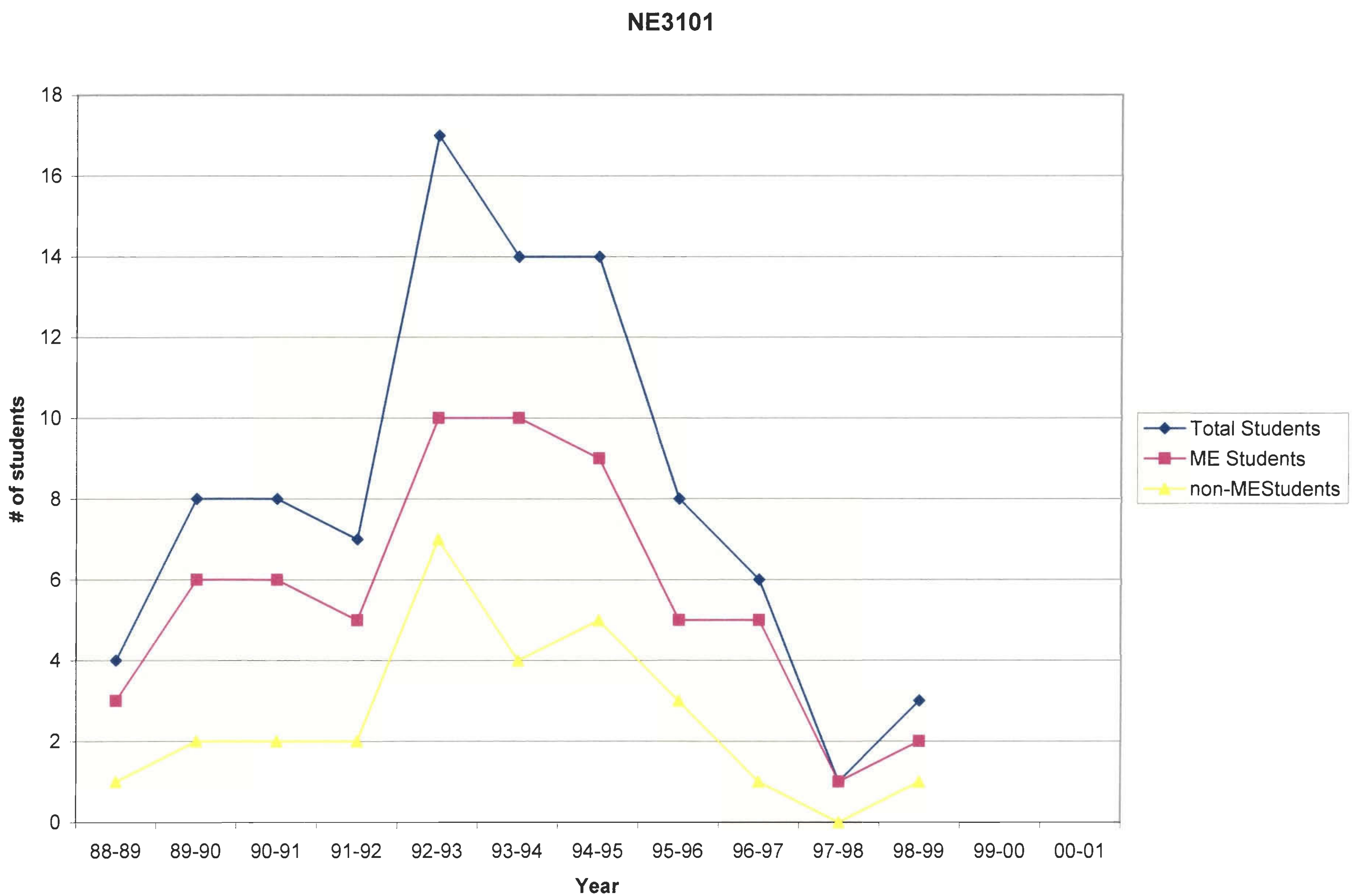
30
25
20
15
10
5
0
# of students
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents

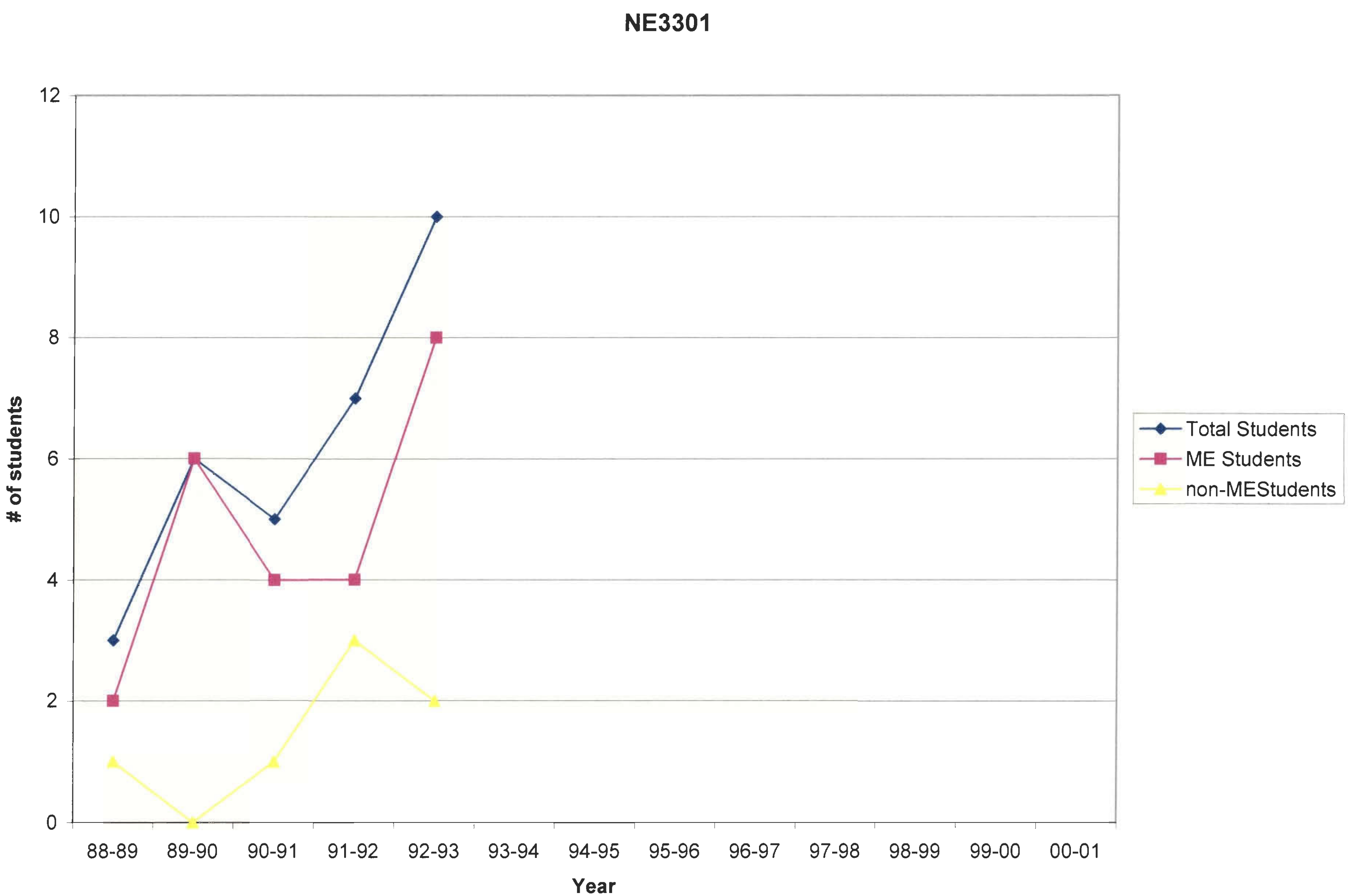

NE2002
# of students
25
20
15
10
5
0
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents

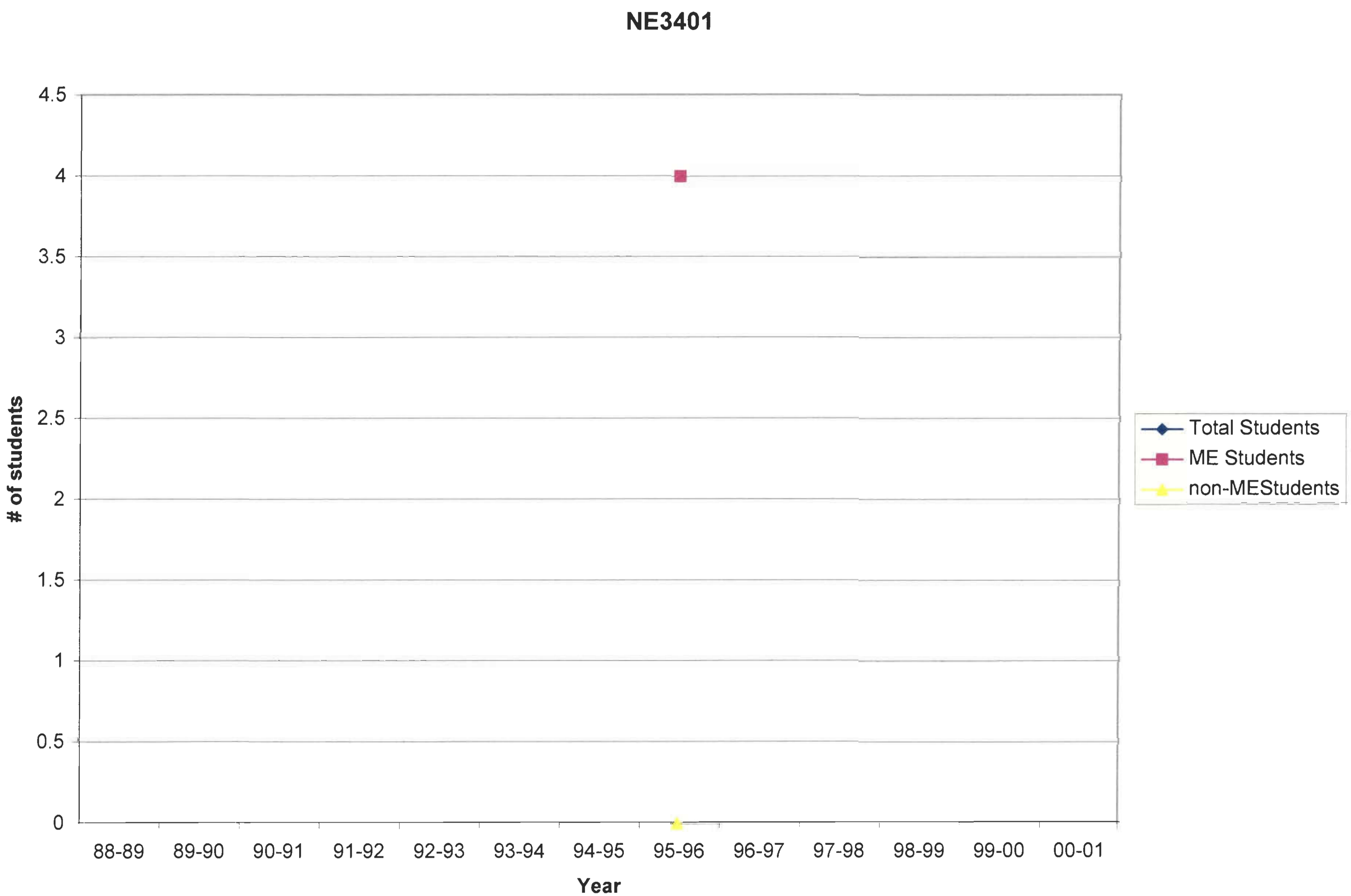


NE2011
25
20
15
10
5
0
# of students
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents

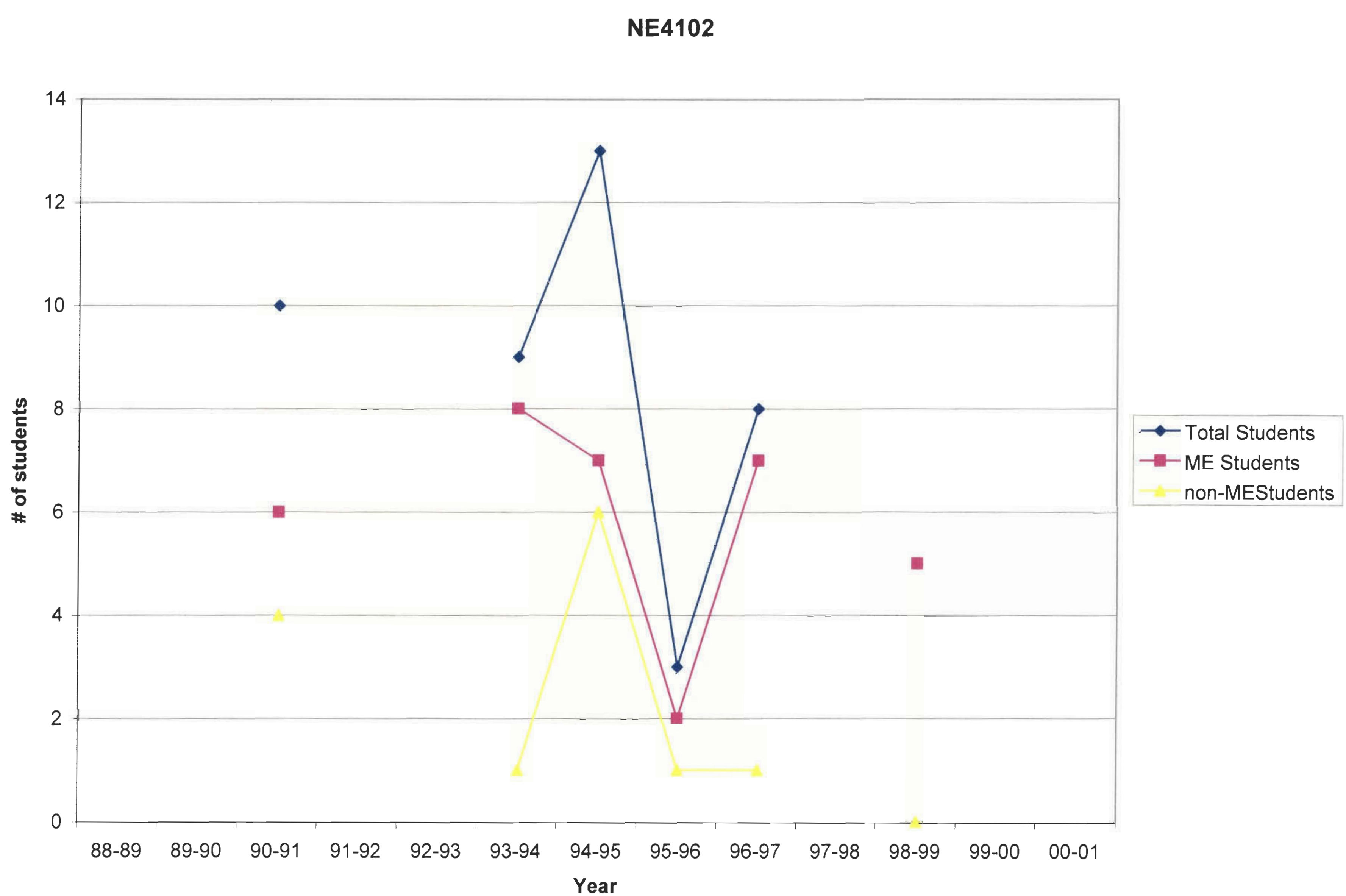

NE2012
12
10
8
6
4
2
0
# of students
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents

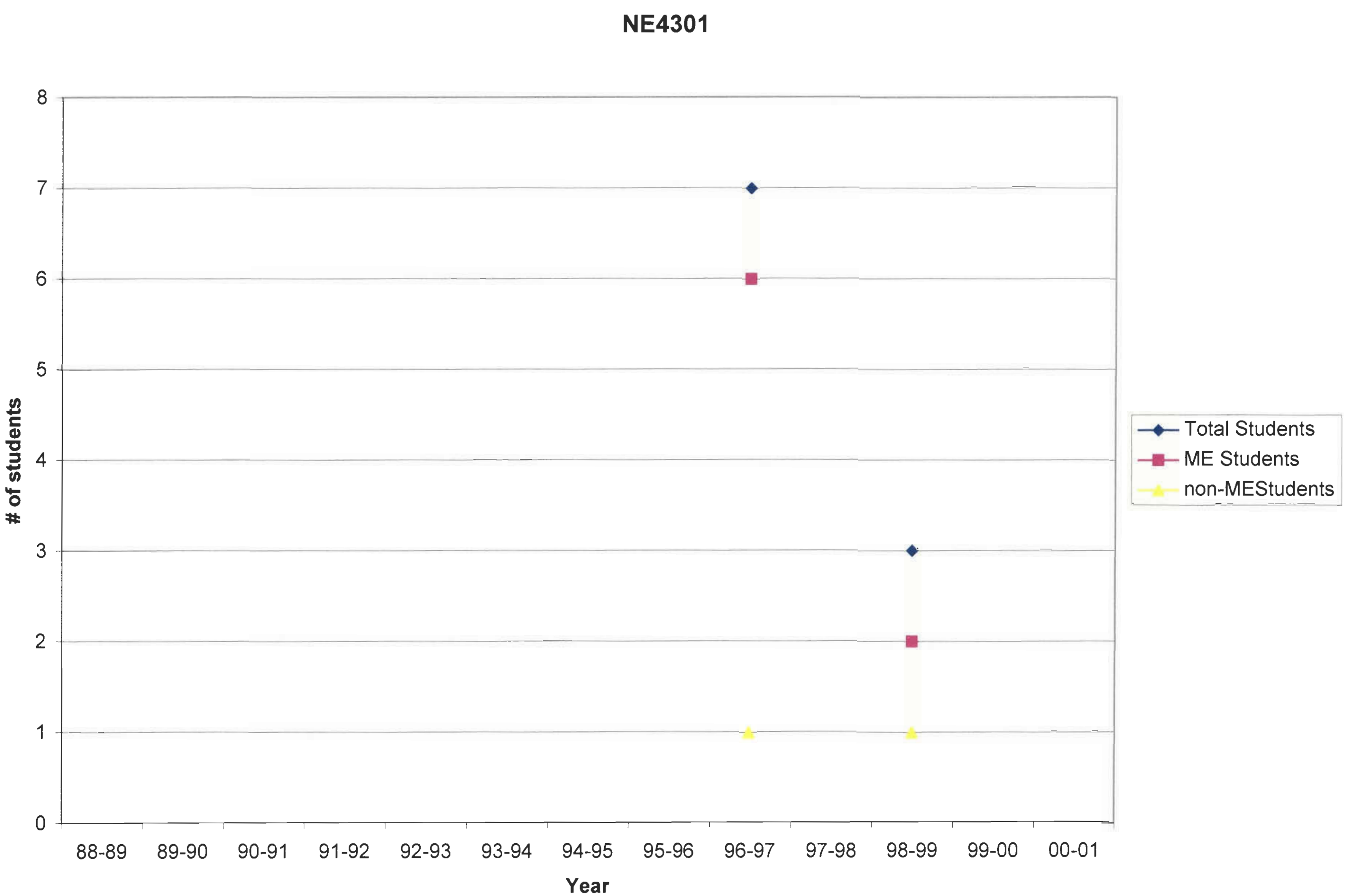

NE3101
18
16
14
12
10
8
6
4
2
0
# of students
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents


NE3301
12
10
8
6
4
2
0
# of students
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents



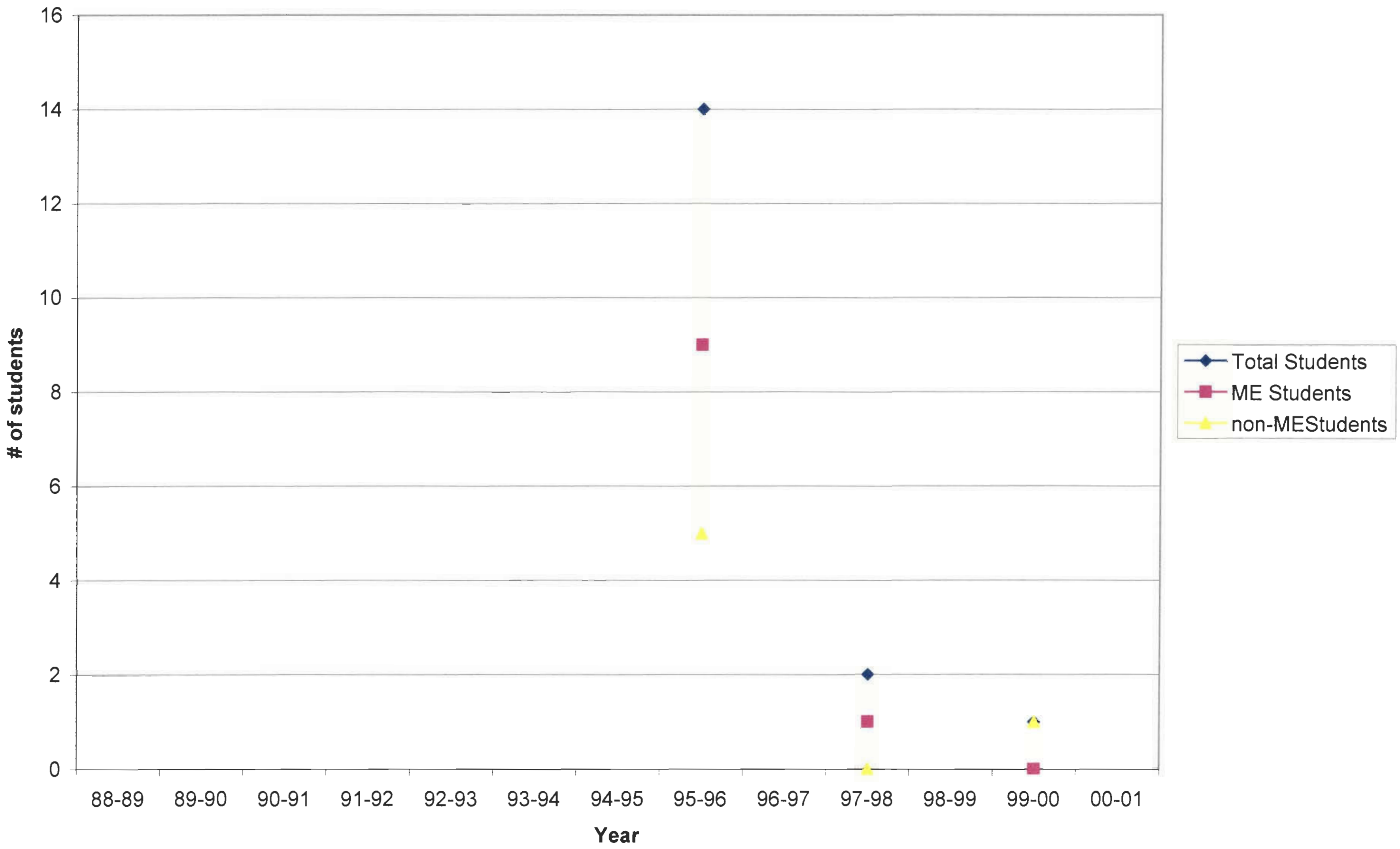
NE3401
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
# of students
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents


NE4102
14
12
10
8
6
4
2
0
# of students
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents

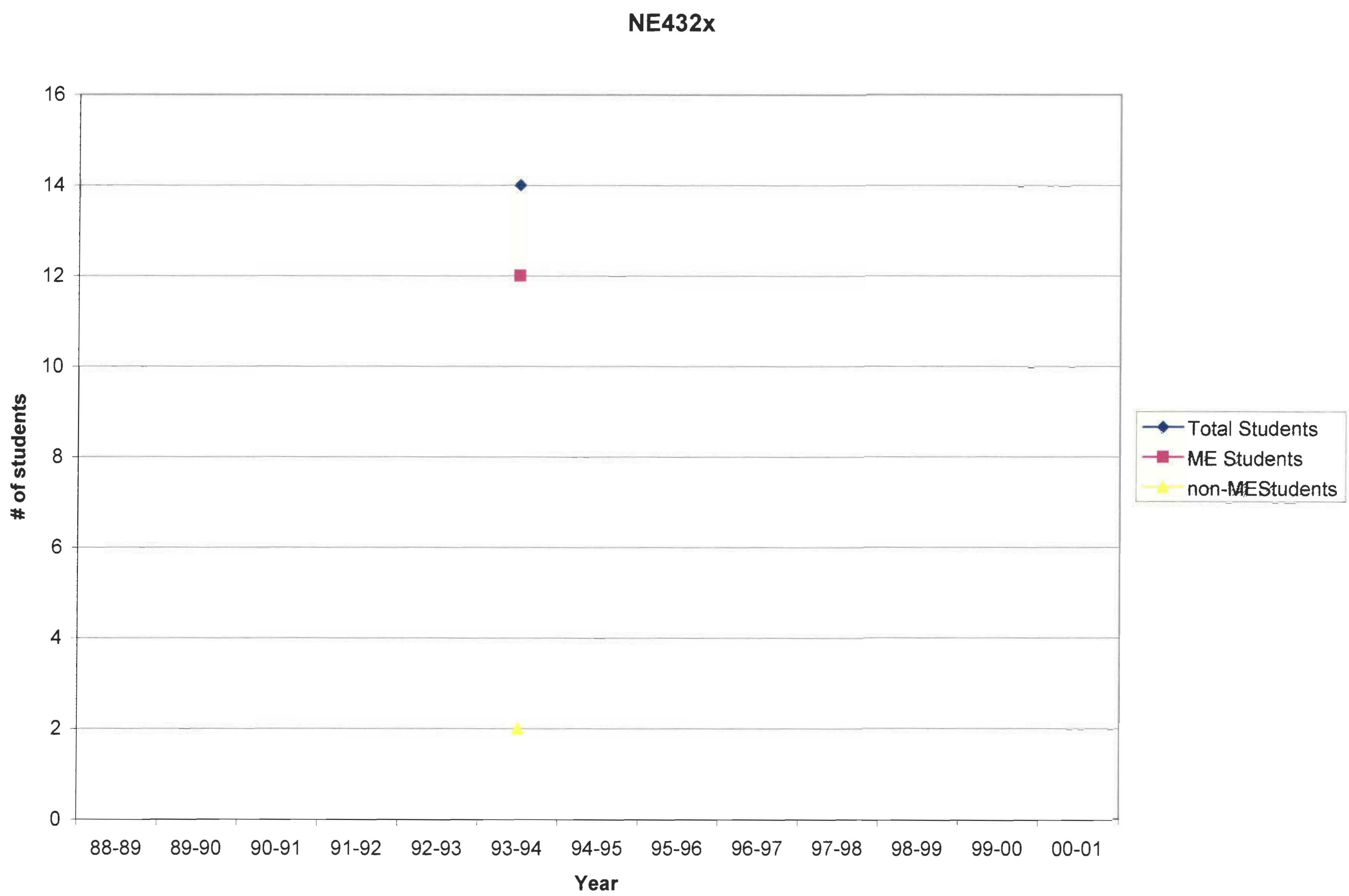


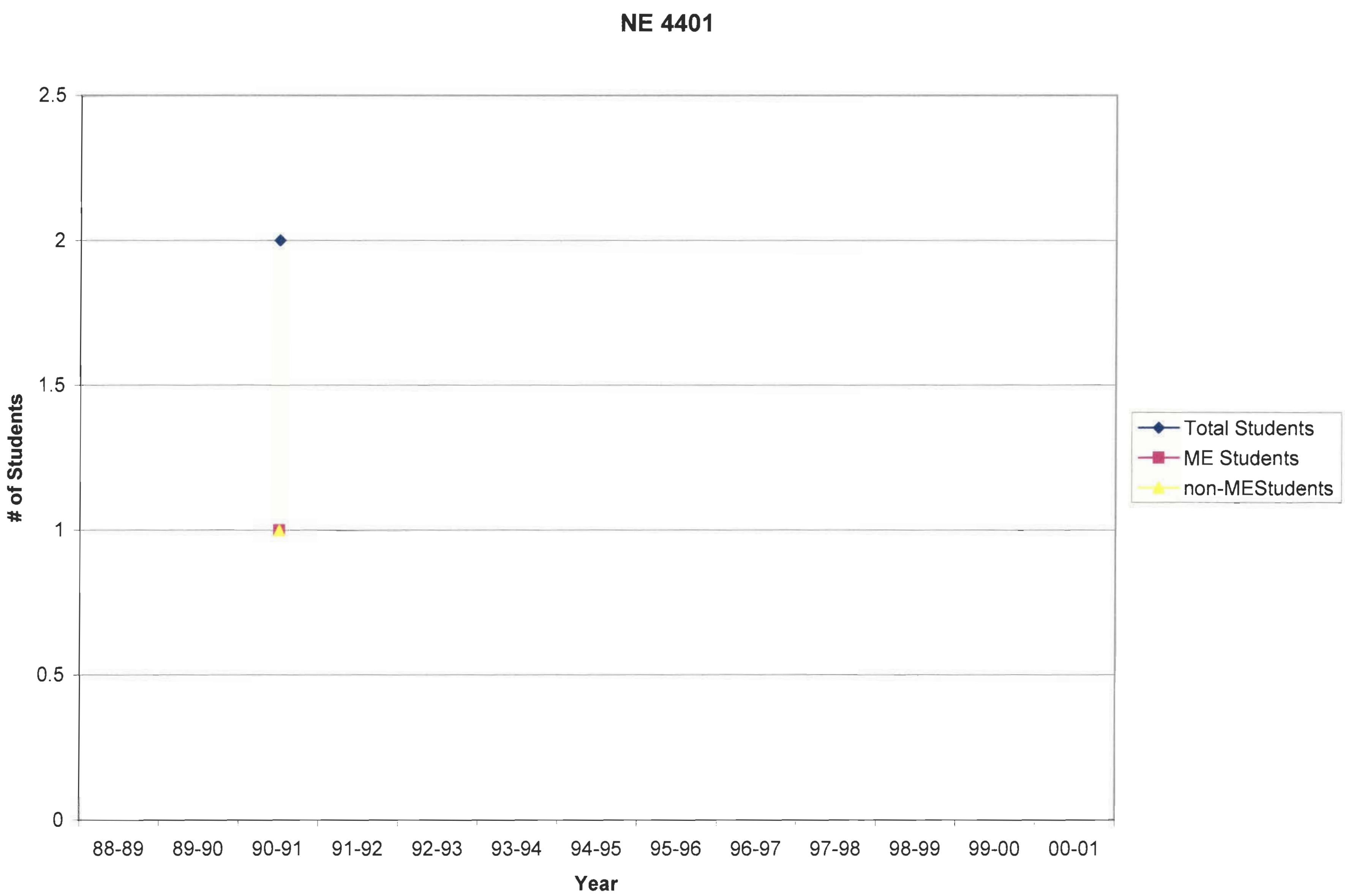
NE4301
8
7
6
5
4
3
2
1
0
# of students
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents

NE4302

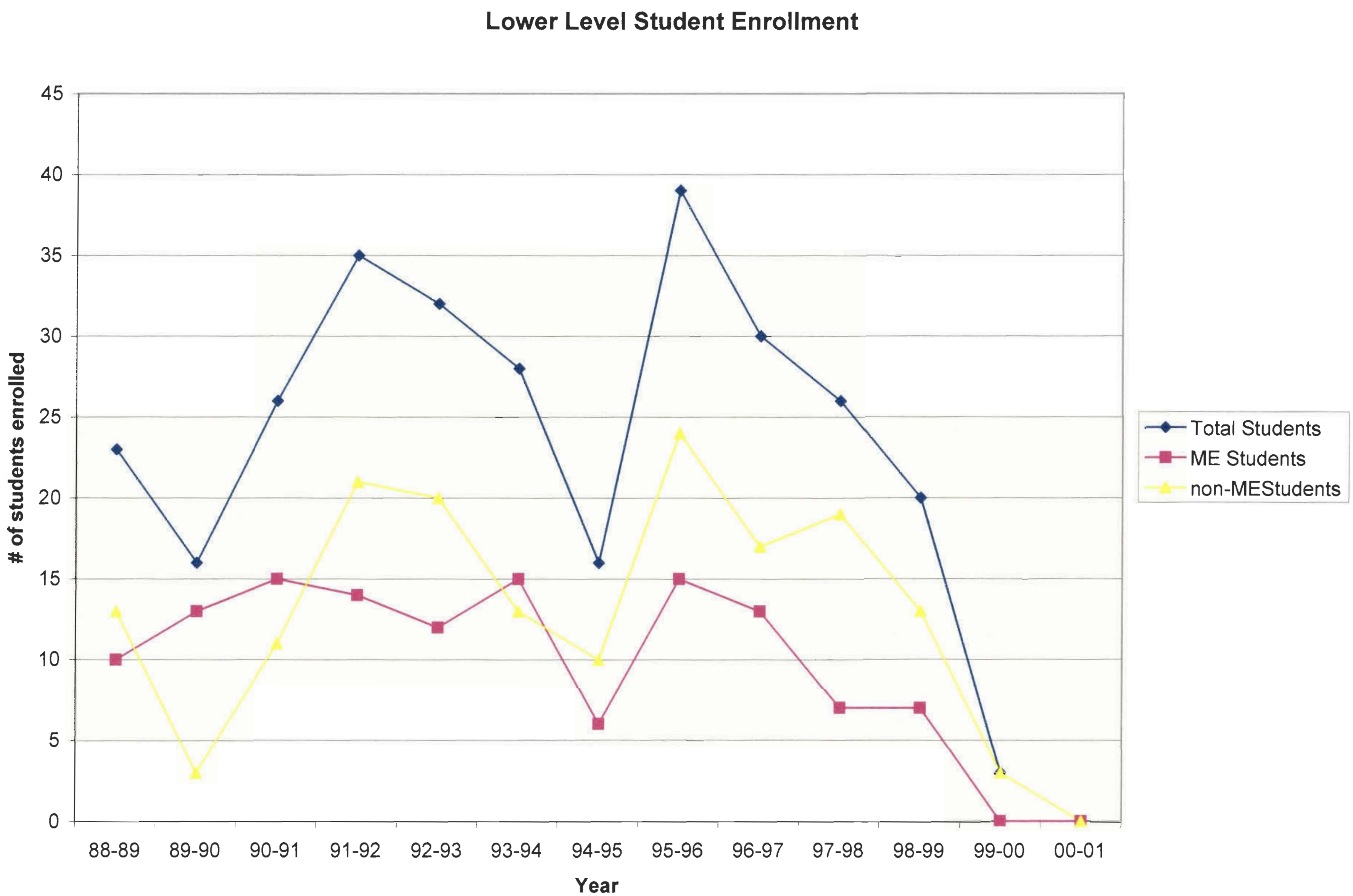


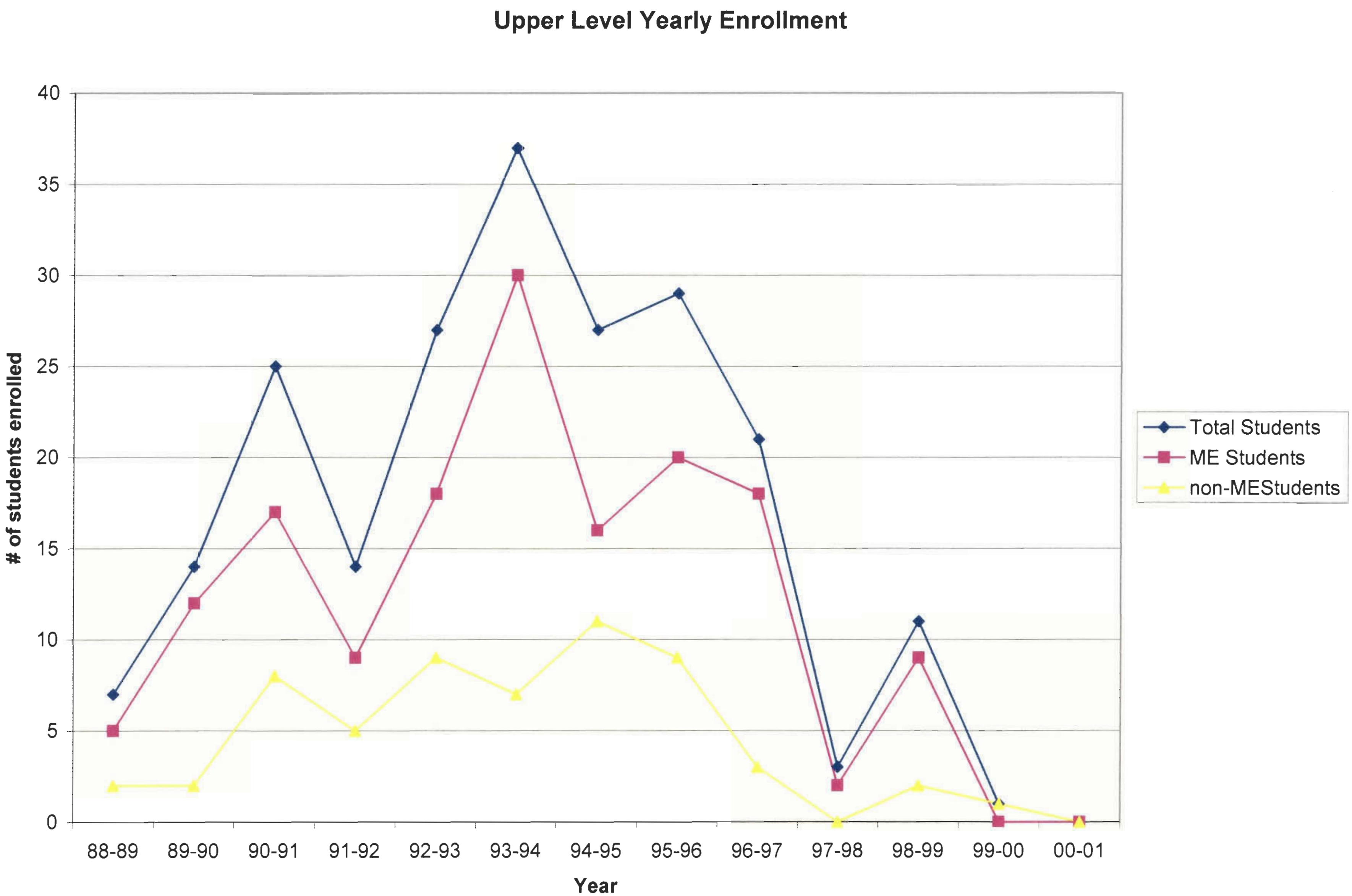
NE4302
16
14
12
10
8
6
4
2
0
# of students
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents


NE432x
16
14
12
10
8
6
4
2
0
# of students
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-ME Students



NE 4401
2.5
2
1.5
1
0.5
0
# of Students
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents


Lower Level Student Enrollment
# of students enrolled
0
5
10
15
20
25
30
35
40
45
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents



Upper Level Yearly Enrollment
40
35
30
25
20
15
10
5
0
# of students enrolled
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
97-98
98-99
99-00
00-01
Year
Total Students
ME Students
non-MEStudents

Appendix B.

The additional courses that will need to be offered are the following:

ES 2011 Intro To Nuclear Science and Engineering

NE 202x Radiological Engineering and Technology

ES/NE 302x Radiation Transport: Attenuation, Effects, and Measurement

NE 402x Nuclear Criticality Theory and Analysis

NE/BB 306x Radiobiology

NE/CM 305x Nuclear Chemistry

It is hoped that suitable and willing faculty can be found in CM and BB to teach 2 of these courses listed above. That would leave 4 courses left, which could be fulfilled with a single new faculty member with Nuclear Science and Engineering knowledge.

This plan is a proposal for the adaptation of a nuclear minor at WPI with minimal need for additional funding, space, or effort. There is much overlap already that occurs, and with a little effort this plan could easily be put into effect. For rationale supporting the need for such a program, please see Matt Stanley (mstanley@wpi.edu) after the end of D'01, or look for a copy of the IQP written to support this plan.

The WPI Requirements for a minor:

A minor is defined as a "thematically-related set of academic activities leading to a degree designation in addition to but separate from that granted by the Major." There are several requirements that must be met by a minor proposal:

1. ***Two or more Units of thematically related activity.***
2. ***The final 1/3 unit must be a capstone project, which marks completion of the minor.***
3. ***At least one unit of the minor must be electives; the remaining unit may be double counted towards a student's major if such overlap exists.***

The proposal set forth in this brochure satisfies all the above requirements. It takes advantage of the overlapping of many courses in various majors, thus allowing double counting of some courses, making it easier for those students who choose to pursue this minor to fit in all the requirements within their schedule. This also minimizes the number of NE courses that need to be offered, thus making the need for additional faculty a minimum.

WPI

Questions or Comments: Direct to

Matt Stanley

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Worcester, MA, 01609
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mstanley@wpi.edu

A Proposal for a Minor in Nuclear Science and Technology

New Choices and Opportunities for Multidisciplinary Study of Nuclear Topics

An IQP by Matt Stanley and Conan McNamara
Advised by Professor T. H. Keil
WPI WORCESTER POLYTECHNIC INSTITUTE

Why Does WPI need to change the current Program?

The current program here at WPI is the remnants from the program established in the 1950's, which focused on the power generation side of the nuclear field. In the past this area dominated the Nuclear Sciences; Today, however, there is a decline in Power interest. This has hurt the WPI Nuclear Engineering Program student interest levels to some degree. What this proposal attempts to do is to change the focus of the program to a more multidisciplinary program, one which covers everything from Radiobiology to Nuclear Medicine to Medical Imaging to Radiopharmaceuticals to Nuclear Physics to Radiochemistry. It is easy to see that Nuclear Science applies to areas other than power – in fact, it is hard NOT to have Nuclear Technology in your life. It is everywhere, from your smoke detector to your Dental x-ray, to your airport security and your ice cream manufacturer.

Why Pursue a Nuclear Minor?

If you are in a Major Area of study such as Biology, Biomedical Engineering, Physics, Chemistry, or another that has nuclear applications in today's society, you can benefit from a stronger knowledge in this field. The minor enables you to not only pursue your initial interest area of study, but to also add on the designation that you are knowledgeable about the nuclear field.

The Job Market for people with a nuclear background is strong and getting stronger. It is a part of everyday life and work, and someone with experience and knowledge in Nuclear Science can get more out of their Biology, Chemistry, Physics, or other Degree.

Course Paths

Biomedical Engineering

ES 2011	Intro to Nuclear Science/Eng
ES/NE 202x	Radiological Eng. and Tech
BE 581	Medical Imaging Systems
ES/NE 302x	Radiation Transport
NE/BB 306x	Radio Biology
	Capstone Project

Physics

ES 2011	Intro to Nuclear Science/Eng
ES/NE 202x	Radiological Eng. and Tech
PH 3503	Nuclear Physics
ES/NE 302x	Radiation Transport
PH 2651	Intermediate Physics Lab
NE 402x	Nuclear Criticality Theory
	Capstone Project

Mechanical Engineering

ES 2011	Intro to Nuclear Science/Eng
ES/NE 202x	Radiological Eng. and Tech
ME 3422	Environmental Issues and Analysis
ES 3003	Heat Transfer
ES 3004	Fluid Mechanics
ES/NE 302x	Radiation Transport
NE 402x	Nuclear Criticality Theory
	Capstone Project

Chemical Engineering

ES 2011	Intro to Nuclear Science/Eng
ES/NE 202x	Radiological Eng. and Tech
CM 3601	Chemical Materials Eng
ES/NE 302x	Radiation Transport
NE/CM 305x	Nuclear Chemistry
	Capstone Project

Civil Engineering

ES 2011	Intro to Nuclear Science/Eng
ES/NE 202x	Radiological Eng. and Tech
GE 2341	Geology
CE 3022	Legal Aspects in Design and Construction
CE 3059	Environmental Engineering
CM 3910	Chemical and Environmental Technology
ES/NE 302x	Radiation Transport
	Capstone Project

Biology/Biotechnology

The biology Tech-Pack in Nuclear Science will once again be offered. Any of the Radiobiology or NE courses can count towards the three-course cluster needed to achieve this per the Biotechnology Degree Requirements.

Thus, anyone in Biology/Biotechnology, Biomedical Engineering, Physics, Mechanical Engineering, Chemical Engineering and Civil Engineering will be able to take advantage of this program, whereas in the past it was only ME students who had the option.

"University research and training reactors must establish a multi-disciplinary infrastructure in order to strengthen their position within the university." ~Pedro B. Perez, Chairman, TRTR Professor, NCSU Quoted from: University Research Reactors: Contributing to the National Scientific and Engineering Infrastructure from 1953 to 2000 and Beyond; *A Report to NERAC Subcommittee to Analyze the Future of University Nuclear Engineering and Research Reactors*