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Comparison of Nuclear Engineering Programs at the Jordan University of Science and Technology and the University of Michigan

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Abstract

At the dawn of the atomic age, the University of Michigan established the first American degree program in nuclear engineering in 1952 and it is today one of the top ranked nuclear engineering programs in the United States. The Jordan University of Science and Technology (JUST) established the first nuclear engineering program in Jordan in 2007 as an integral component in the country's roadmap for introducing nuclear power to its domestic energy portfolio. Jordan's nuclear energy goals are driven by the reality that 95% of its domestic energy needs are covered by imported fuel sources which account for nearly 20% of its GDP. JUST's nuclear program's mission encompasses human capital development in the fields of nuclear science and engineering to ensure a highly qualified pool of skilled scientists and engineers to construct, operate and regulate Jordan's first commercial nuclear power plant. In contrast, the Michigan Nuclear Engineering and Radiological Sciences department is marked by its accomplishments in a broad array of nuclear research areas with a $17 million annual research portfolio. Both universities are tied together by their respective INMM student chapters, with Michigan having founded one of the first ever student chapters and JUST having established the first international INMM student chapter. This work presents a comparison between these two nuclear engineering programs. The histories of these two programs are explored and contrasted. The two departments' academic goals and their implementations are discussed. Differences and similarities in our respective departments' student bodies, department missions and student career plans are explored. Conclusions are drawn on what we can learn from each other to ensure that both our departments continue to improve and remain beacons of excellence in nuclear engineering education.

1. Introduction

In 2007, the Jordanian energy crisis reached its pinnacle with Jordan importing more than 96% of its energy needs at a cost of $ 3.2 billion, a price tag equivalent to 20% of its total GDP. Demand for oil-fuelled electricity production is expected to rise to 4743 MW in 2020 compared to 2100 MW in 2008 [1-2]. To address these ongoing challenges, Jordan decided to introduce nuclear power which is to provide 30% of its electricity by 2030. The Jordan Atomic Energy Commission (JAEC) and Jordan Nuclear Regulatory Commission (JNRC) were established. Jordan is aware that any nuclear energy project will require qualified nuclear engineers and scientists. Therefore Jordan University of Science and Technology (JUST) established the first and only nuclear engineering program in Jordan in 2007 as an important step in making nuclear power a viable energy source in Jordan.

Four professors participated in the foundation of the Nuclear Engineering Department (NED) at JUST. Dr. Ziad Kodah and Dr. Ned Xoubi spearheaded the establishment of the department in 2007. Dr.

Xoubi served as first department Chairman from 2007-2008. Both of them prepared the department's first undergraduate curriculum in collaboration with the nuclear engineering department at North Carolina State University. Dr. Malkawi has served as chairman of NED since 2008. Dr. Malkawi led the establishment of the department's laboratories, and he was the president of the construction project of the Jordan Subcritical Assembly (JSA) at JUST campus. Finally, Dr. El-Gohary and Dr. Malkawi designed the currently in use 2013 curriculum [3]. NED at JUST is the first of its kind in Jordan. JUST's department of applied physics was founded in 1997. The department included two main branches related to nuclear energy and radiation science, namely Radiation Protection and Non Destructive Testing.

2. Summary of UM Nuclear Engineering and Radiological Sciences.

I. Department History

At the University of Michigan the nuclear engineering program's creation is closely tied with the establishment of the Michigan Memorial Phoenix Project (MMPP) in 1948. The GI bill or Servicemen's Readjustment Act of 1944 flooded the campus with World War II veterans. Students were exploring ideas to memorialize the country's fallen soldiers. The university regents sent out a letter to alumni soliciting ideas. Fred Smith, a local alumnus and president of the Book of the Month Club, had been offended by an open letter penned by Nobel laureate Joliot Curie criticizing the United States for militarizing nuclear science (nuclear weapons, nuclear powered submarines). He recommended a foundation to look into the peaceful applications of nuclear science. This idea gained traction among students and faculty and millions of dollars were raised from over 25,000 individual donors including a large $1 million donation by the Ford Auto Company to construct and endow the MMPP's Ford Nuclear Reactor (FNR). Reactor designs had been classified but the federal government saw a need to train nuclear engineering PhD graduates to staff their nuclear weapons and nuclear navy development programs. The first American university research reactors were constructed in the early 1950s at North Carolina State University and Penn State University. The FNR reached first criticality in 1957 and became the third operating university research reactor in the United States. The MMPP was only to support peaceful nuclear science such as nuclear medicine, nuclear power, nuclear physics, archeology and food irradiation. Military research was strictly forbidden. The Soviet satellite Sputnik was also launched in 1957 resulting in unprecedented and unanimous support for federal science funding. Many faculty members at the University of Michigan promoted the MMPP and FNR construction and saw this as an opportunity to start the first American nuclear engineering graduate program in 1952. Subsequently the department was founded in 1958. Several faculty members already previously worked on nuclear science within other departments and taught classified nuclear science courses to Air Force officers during the late 1940s [4-5].

Two founding members, Henry Gomberg and William Kerr, both worked in the electrical engineering department and were instrumental in founding the nuclear engineering department. They went on to become the first and second heads of the department. They were described as politically savvy and had the support of the graduate school dean, Ralph Sawyer, who previously was a physics professor and had worked as the civilian Technical Director for the atomic bomb tests on Bikini atoll. Under William Kerr, many prominent faculty members such as Glenn Knoll, James Duderstadt and Louis Hamilton were hired. Their seminal books, "Radiation Detection and Measurements" and "Nuclear Reactor Analysis", are standard textbooks at nuclear engineering programs all around the world. The birth and rapid expansion of commercial nuclear power in the United States in the 1960s and

1970s (about 200 reactors were ordered though only about 100 were ever completed) suddenly created a demand for an undergraduate program which was established in 1965 [4,5].

Before the bright present, however, the Department of Nuclear Engineering and Radiological Sciences (NERS) survived its darkest days in the 1980s and 1990s. High interest rates, low electricity demand growth, regulatory challenges and a public backlash over the Three Mile Island and Chernobyl industrial accidents led to the cancellation of dozens of nuclear power plant constructions. While many plants approved prior to 1975 were eventually completed up into the 1990s, not a single new plant was approved and built from 1975 until the presently under construction AP1000 units at plants Vogtle and V.C. Summer in Georgia and South Carolina were approved. Nuclear power expansion was stalled in the United States and President Clinton reduced nuclear research funding from over $1 billion per year to zero in the mid-1990s. These were trying times for nuclear engineering programs. In the United States, from 1978 to 1988 the number of university research reactors plummeted from 76 to 27, the number of nuclear engineering programs dropped from 80 to 57, and student enrollment fell dramatically, especially for undergraduate enrollment. These trends continued into the 1990s and Michigan was not left unaffected. The FNR was shut down in 2003 [4-7].

Graduate student enrollment has been higher than undergraduate enrollment in most years, indicative of Michigan's reputation as a top-tier research institute. Graduate enrollment was relatively stable between 80 and 100 students throughout the 80s and early 90s and then slowly declined to 60 in the mid to late 90's. Enrollment rebounded and expanded rapidly to over 130 students under Presidents Bush and Obama as nuclear research funding was restored. Nuclear engineering has always been one of the smaller disciplines in the college of engineering. In the 90s, total undergraduate enrollment fell to as low as 26 students from a high of over 70. These were challenging times for the department's continued existence when many courses had fewer than 10 students enrolled. The department stayed afloat by diversifying its research into areas like nuclear medicine, plasma research and health physics. At the turn of the millennium, renewed interest in nuclear science and a predicted nuclear power renaissance in the United States led to a rapid undergraduate enrollment expansion to a peak of 121 students in 2010. With the nuclear renaissance stalled at merely five new reactor constructions and the Fukushima accident occurring in 2011, undergraduate enrollment has dropped again slightly, though the department's goal is to keep it at above 100 students [8].

II. Department Today

Faculty and Research

Today the department employs 23 faculty members. The gender imbalance amongst faculty (3 female and 20 male faculty members) and lack of under-represented minorities (1 African American faculty, 0 Hispanic faculty) is a widespread phenomenon in engineering both on the faculty and student level. The department's faculty members are spread relatively evenly across four major research areas: fission systems and radiation transport, materials, measurements and plasmas & fusion [8-11].

The department has a heavy emphasis on research. For fiscal year 2013 the total research expenditures of NERS were $17,569,605. Of the 165 research grants only 9 came from industry with the remainder being federal research grants. More than half of all grants, totaling over $9 million, came from the United States Department of Energy. A further $4 million in grants was awarded to NERS by the Department of Defense. NERS professors received grants totaling over $1 million from the both the

Department of Homeland Security and Nuclear Regulatory Commission. The Electric Power Research Institute, National Science Foundation and National Aeronautics and Space Administration awarded Michigan researchers grants adding up to between $100,000 and $600,000. This research is conducted primarily by over a hundred NERS graduate students at over a dozen laboratories [8].

III. Students

Demographics

Women and underrepresented minorities (URM) remain woefully underrepresented. Only 21%, 24% and 16% of B.S., M.S. and Ph.D. engineering degrees were awarded to women in the 2013-2014 academic year. Regarding URMs, the demographics of the state of Michigan include 14% African American and 4% Hispanic. Asian-Americans accounted for 13% of engineering students, more than double their 5% portion of the general U.S. population. African-Americans are extremely underrepresented at 2% of engineering students. Students at the University of Michigan literally come from the entire world though about 49% of all students come from the state of Michigan. About 14% of the entire student body is composed of foreigners. These students come from 121 countries, with China, India and the Republic of Korea being the top three origin countries.

Curriculum

The B.S.E. in NERS requires a total of 128 credit hours typically spread over 8 terms or 4 years. Of these credits, 52 to 55 credits are outside of the college of engineering with an emphasis on mathematics, humanities, social sciences, physics and chemistry. Undergraduate students are also required to take 11 credit hours in other engineering departments including introductory thermodynamics, materials science and linear circuits courses. The 45 required credit hours within NERS are distributed relatively rigidly. Students are required to take classes in nuclear physics, radiation detection, neutronics, reactor design and thermal-hydraulics. 9 credit hours are electives within NERS. Students may elect to take classes in radiation health physics, plasmas and fusion, nonproliferation and safeguards, nuclear history, radiation material effects and any other of the over 50 courses offered in NERS. Undergraduate students must complete two laboratory classes including a radiation detection laboratory and a second laboratory class of their choice. Senior students are also required to complete one of two senior design classes. Students can choose between a reactor design course and a radiation detection simulation course [12].

PhD students are required to complete 18 credit hours before advancing to candidacy. PhD students must pass a six hour closed book candidacy exam. This exam is written by the faculty and exists in four custom-tailored versions for students pursuing research in fission systems and radiation transport, materials, measurements and plasmas and fusion. The curricula are individually geared for these four options to prepare students for their respective candidacy exam. All PhD students are also required take at least two classes in NERS outside of their candidacy exam option. Finally, the university also requires students to take four credits outside of their department. Students may pick to learn about science and technology public policy in the public policy school, or perhaps take a course in signal processing in electrical engineering. The possibilities are nearly endless [13]. A variety of options exist for obtaining a non-thesis M.S.E degree.

Student organizations

Students in NERS have four nuclear-related student organizations to choose from. The INMM chapter is predominantly composed of graduate students in the measurements option. Students at U of M also formed the first student chapter of the American Nuclear Society (ANS) in 1955. This organization is predominantly geared towards professional development opportunities in the nuclear industry for undergraduate students. The ANS chapter also organizes many social events, tours of commercial nuclear power plants in Michigan, and community outreach events. The Alpha Nu Sigma chapter is an honors society affiliated with ANS. Finally, the Health Physics Society student chapter focuses on professional development specifically for health physics. At a university with a student body totaling over 43,000 over a thousand student organizations ranging from club sports, philanthropic organizations and cultural societies draw members from across all disciplines. Whether a student wants to build a solar car, play water polo or feed squirrels, a student organization exists or could easily be founded [8].

Summer engagements

U of M undergraduate students have a four month summer break. About 70% of undergraduate nuclear engineering student reported having participated in undergraduate research, internships or study abroad programs in 2013. 24 students performed research at the university. Other students were hired for paid internship positions at Department of Energy national laboratories, nuclear power plants and the nuclear industry. Eleven students also participated in study abroad programs. The nuclear engineering department offers its own "Summer School on Nuclear Power Development in China" study abroad program. Professors Wang and Fleming have been taking small groups of undergraduate students for the past few summers to China to view that country's booming nuclear industry [8].

Post-graduation employment

In 2013, 31 out of 52 combined nuclear engineering and engineering physics B.S.E. graduates continued with graduate studies. The remaining graduates found employment at nuclear power plants, the United States Armed Forces, nuclear-related industry and elsewhere. Historical numbers from the department from 1970 to 2013 show that about half of B.S. graduates have continued on to graduate education. For PhD graduates the Department of Energy and the federal government are typically their first employers out of university. Over a hundred graduate students have also found their first post-graduation employment in academia [8].

3. Summary of JUST Nuclear Engineering Department

Funding resources are the cornerstone for any research work. In Jordan many bodies provide financial support to students to fund their graduation projects and their research work. These bodies include but are not limited to the Jordanian Ministry of Higher Education scholarship programs**,** King Abdullah II Fund for Development (KAFD) and The King Abdullah II Design and Development Bureau (KADDB). The Deanship of scientific research at JUST also funds students to conduct research, or to start their own projects. In 2013 the deanship of research at JUST provided around 4.5 Million USD which was funded by internal and external organizations [14]. Additionally, the Jordan Atomic Energy Commission (JAEC) offered scholarships to the Nuclear Engineering students with the highest GPA in each year.

Even though its number of staff members is small compared to University of Michigan, JUST also has faculty members who can work in nearly all of the major research areas of nuclear engineering. JUST NED employs 8 faculty members and one research engineer. They are experts in various nuclear

engineering topics such as nuclear reactor thermal hydraulics, neutronics/reactor design, nuclear reactor computational methods, nuclear safety and security, radiation detection, shielding and dosimetry, fuel cycle and management, nuclear materials and plasma physics.

JUST NED houses four laboratories and a research reactor which is anticipated to be fully operational in 2016. The four labs are fully operational and accessible. The radiation detection lab teaches students the fundamentals of radiation detection and gamma spectroscopy. The IRL is the second lab commissioned at NED. It allows the Jordanian students to interact remotely with the staff at the PULSTAR reactor at North Carolina State University [15]. Many experiments were conducted online with the PULSTAR reactor to teach students enrolled in the Nuclear Reactor Laboratory course. The third lab is the Jordan Subcritical Assembly (JSA) which is one of the newest subcritical assemblies in the world. It is located in Irbid city on JUST's campus. Commissioned in June 2013, it represents another step in Jordan's efforts to develop its basic nuclear infrastructure [16]. The high speed parallel computational lab is designed for teaching of advanced computational techniques, modeling, simulation and design of nuclear reactors. Finally, the newest addition is the Jordan Research and Training Reactor (JRTR). JRTR is an on-campus open pool research reactor with 5-MW_{th} power (upgradable to 10-MW), with in-core thermal neutron fluxes reaching 10^{14} $\frac{n}{cm^2-s}$. The JRTR offers several opportunities such as human resources training, radioisotope production for medical and industrial applications, neutron activation analysis, and neutron transmutation doping [17].

JUST NED began admitting students one year before its establishment (2006). The department admitted 21 students, and the first class graduated 19 students in 2011. Fig.1 shows the number of students admitted and B.Sc. graduates from 2006 to 2015. Currently a total of 100 students are now enrolled [18]. The number of students admitted and graduating each year is somewhat low because of the low acceptance rate of applicants to the department. The department is pursuing the low acceptance rate policy to ensure ample job opportunities for alumni thus avoiding high unemployment rates among NED graduates. There is about one faculty member for every 12 students**.** The age range of faculty members varies between 29 and 65 and there is only one female faculty member. Students' ages range between 18 and 23 years old. More information regarding the demographics of the faculty members and the students are listed in Table 1. The percentage of international students in the department is 9%. The nationalities of the international students are limited to nationalities of neighboring Arab countries like Saudi Arabia, Yemen, Palestine and Sudan [18].

Table 1: Faculty and Students demographics including age range and gender

	Age Range	**Gender**		**Total Number**
Faculty Members	(27-65) years	M	F	8
		7	1	
Current Undergraduate Students	(18-23) years	M	F	100
		59	41	

NED graduates find themselves at a crossroad of either choosing to pursue graduate school or find a job opportunity in the private or public sectors. JUST NED has graduated a total of 95 students (expected to be 111 alumni by June 2015). Most of JUST Nuclear Engineering graduates are now employed at nuclear institutions or nuclear-related institutions like the Jordan Atomic Energy Commission, the Energy and Minerals Regulatory Commission (EMRC), the Jordan Research and Training Reactor, research laboratories, the Jordan Nuclear Power Commission (JNPC), JUST NED, the

Jordan Subcritical Assembly, Emirates Nuclear Energy Commission (ENEC). A smaller number of students are now employed in non-nuclear professions like school teachers, mechanical engineers, and private industry. More employment information is located in Fig.2.

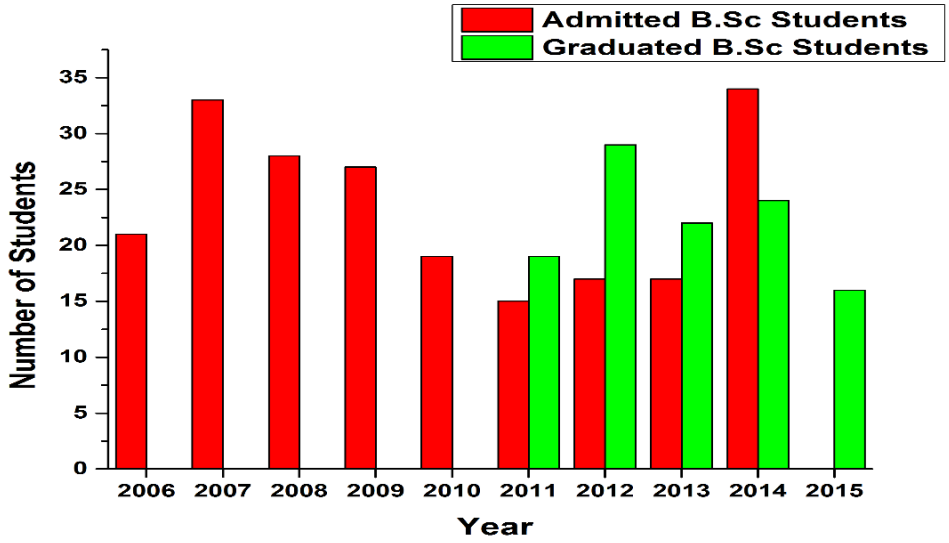

Fig.1: Admitted and graduated students' numbers in JUST NED since its establishment.

JUST NED aims to educate students in the fundamental subjects necessary for a career in nuclear engineering and to prepare students for advanced education in nuclear engineering and other related fields. The main topics that are covered in the curriculum are the basics of nuclear technology, radiation measurements, nuclear reactors, methodology of nuclear power plant design, nuclear materials, nuclear safety and security, basics of nuclear instrumentation, laboratory techniques, data interpretation and analysis, and the ability to apply knowledge of mathematics, science and engineering to the analysis of nuclear and other engineering systems.

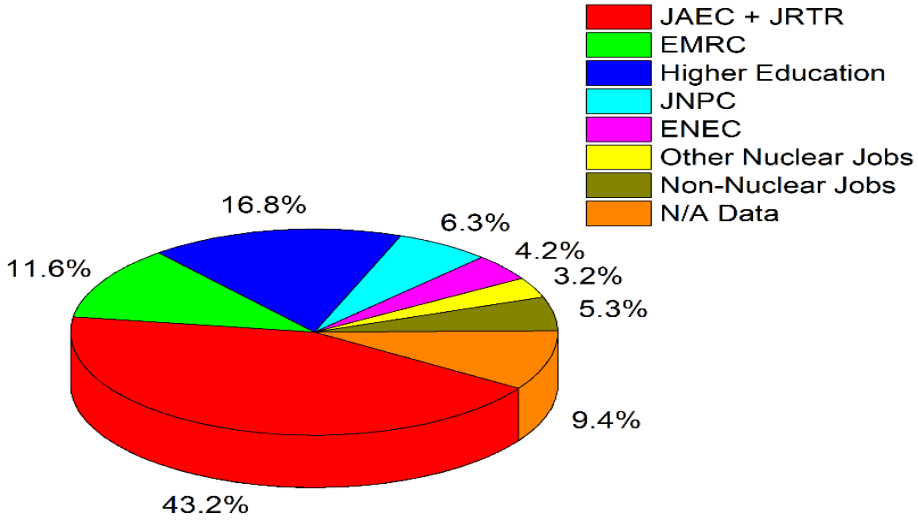

Fig.2: Places of employment of JUST Nuclear Engineering graduates.

The first B.Sc. curriculum of NED was utilized in 2007 when the department was established. The 2007 curriculum was valid until 2013 when JUST decided to re-develop the undergraduate curricula of all university academic departments. The 2013 curriculum contains a total of 160 credit hours and it has considerable changes in the descriptions and the contents of the courses [19]**.** The curriculum

courses are classified into six categories as listed in Table 2. These categories are structured such that students take basic courses in science and engineering in their first two years thus preparing them to later succeed in core courses in nuclear engineering.

Table 2: Classification of the academic courses in 2013's curriculum by category in the JUST NED.

Course Category	Recommended Year	Number of Credit Hours	Percentage
University Compulsory	1st year	16	10%
University Elective (Humanities and Social Sciences)	It varies but recommended in 4th and 5th years	9	5.625%
Basic Science	1st and 2nd years	29	18.125%
Basic Engineering	2nd and 3rd years	32	20%
Nuclear Engineering Compulsory	Starting from 2nd year to the 5th year	68	42.5%
Nuclear Engineering Elective	5th year	6	3.75%

The department also has hosted a diverse set of nuclear-themed activities. Four debates about the Jordanian Nuclear Energy Program and Power Plant were held at different venues in Jordan and they were attended by NED students. Two initiatives for the importance of nuclear energy and the high level of safety and security in the nuclear facilities are spearheaded by NED. Four conferences with different topics and objectives were held at the department itself. Students of JUST NED formed the first international INMM student chapter which is considered to be one of the more active INMM chapters based upon nuclear–related activities and publication rate of conference research papers.

4. Discussion

The impetus behind the establishment of NERS at University of Michigan was to perform research in peaceful nuclear applications following World War II. NERS was established by two non-nuclear professors, however, NED at JUST was established by two nuclear professors to fulfill Jordan's needs for skilled nuclear engineers and to create a strong nuclear infrastructure to drive the Jordanian nuclear energy program. NED will contribute in reducing the huge energy bill which burdens the country from year to year by introducing nuclear energy into Jordan's energy mix. NERS has received funding from both government institutions and industry, whereas most of JUST NED funding comes from the government. The age of the department and number of students enrolled play a major role in the number of faculty members hired. However, the two departments worked in nearly the same research areas despite the big difference in number of faculties.

Student enrollment is somewhat stable for both departments even though there were some drops in student numbers in some years. NERS exhibited some dark days in student enrollment especially in the 90s when the undergraduate enrollment fell to 26 students. This was a challenging problem especially considering that NERS is one of the most well-known nuclear engineering departments in the USA. JUST NED as well suffered from the same problem in 2011 when the future of the Jordanian Nuclear Energy Program was vague and students hesitated to seek a career in nuclear engineering. Both of the departments survived this stalemate, and the student enrollment has been restored to desired levels after two or three years. At the undergraduate level, faculty to student ratio is approximately 1/4 in NERS and it is 1/12 in JUST NED. The ratio in JUST NED is considered among the highest and the best within the JUST College of Engineering.

The demographics of faculty members and students mirror each other at Michigan and JUST. NERS has only three female faculty members while JUST NED has only 1 female faculty member. JUST NED has a good percentage of female students which is currently at 41%, compared to the 20% typical in most Michigan engineering departments. NERS has a higher percentage of international students than JUST NED due to its excellent academic reputation and its age. Students of both departments engaged in many different activities throughout the semesters or in summer sessions. From internships to volunteer work to fulltime jobs, many options are available and usually nuclear engineering students left a good impression on their employer at the end of their training or internship sessions.

The curriculum for B.Sc. in NERS is spread over 4 years with a total of 128 credits whereas JUST NED has a 160-Credit curriculum which takes 5 years on average to complete. Table 3 shows a comparison between the two curricula in terms of the percentage of each course category from the total number of credits. Both elective and compulsory nuclear engineering courses constitute about 45% from the total curriculum credits in both departments.

Table 3: Comparison of the number of credits and percentage of each course category in the academic curriculum for undergraduate programs at both NERS and JUST NED

Course Category	**JUST NED Number of Credits**	**JUST NED Percentage**	**NERS Number of Credits**	**NERS Percentage**
University Compulsory	16	10%	-	-
Humanities and Social Sciences	9	5.625%	16	12.5%
Basic Science (Math, Physics,…etc)	29	18.125%	31	24.2%
Basic Engineering	32	20%	19	14.9%
Nuclear Engineering Compulsory	68	42.5%	45	35.1%
Nuclear Engineering Elective	6	3.75%	17	13.3%
Total	**160**	**100%**	**128**	**100%**

5. Conclusion

Both Michigan NERS and JUST NED benefited from optimistic visionaries. The likes of Gomberg, Kerr and later Duderstadt and Knoll laid the foundations for one of the most consistently highly ranked nuclear engineering programs in the world. The shear fascination of the yet unknown benefits that nuclear technology could gift humanity drove the formation of NERS and inspired countless donors to finance the construction of one of the first ever university research reactors, the Ford Nuclear Reactor. While the FNR is being decommissioned and turned into new laboratory space, the young JUST NED is putting the finishing touches on its brand new JRTR. Compared to the piecemeal American nuclear birth driven by competing interests of nuclear weapons, the nuclear navy, nuclear power, research and academia, the Jordanian nuclear program appears to be well planned and streamlined towards a single national goal, namely the introduction of nuclear power. Facilities, like the JSA and JRTR, are gradually being brought online to train the scientists and engineers that will first license, then construct and finally operate Jordan's nascent nuclear power sector. Michigan's NERS does not operate under a single core federal mission but instead operates as a research institution

providing valuable insights for various government and industry nuclear interests, such as material research for reactor lifetime extensions, new radiation detection systems for homeland security applications, support work for international fusion projects and developing reactor safety codes for the Nuclear Regulatory Commission. JUST NED has benefited much from Michigan's NERS experience as this paper will push JUST NED to establish the first graduate program in nuclear engineering in Jordan by following the same footsteps left by Michigan's example of world-class nuclear engineering education. JUST NED is prudent in taking a cautious approach to enrollment numbers to ensure high employability for its graduates. Michigan's NERS department has weathered its fair share of swings in fortune for both the nuclear industry and nuclear research. Yet the most resilient programs have learned how to constantly reinvent themselves and JUST NED can plan for a bright future if it keeps that mantra in mind.

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