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# What Is Exactly the Scope of Nuclear Chemistry and Its Educational Position between Other Chemistry Branches*

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## Abstract

The undergraduate chemistry programs of different universities across the world show clearly that nuclear chemistry education doesn't have a permanent status in chemistry curricula like classical sub-branches of chemistry which means like organic, inorganic, analytical, physical, and biochemistry. Before starting the evaluation of the status of nuclear chemistry education, first of all, nuclear chemistry should correctly be defined and its position in chemistry education programs should correctly be determined. In addition, a confusion of terminology or at least, a terminological turbulence exists in this branch of chemistry about the use of terms such as nuclear chemistry, radiochemistry, nuclear and radiochemistry. Also, the scopes of the expressions used in this field such as radiochemistry, radiation chemistry, radiopharmaceutical chemistry, etc. should be exactly defined and the realtions between them should be clearly understood. Breifly, nuclear chemistry may be difined as a large umbrella which covers all chemical studies related to radioactive materials and nuclear radiation including the fine sub-branches such as radiochemistry, radiation chemistry, radioanalytical chemistry, radiopharmaceutical chemistry, environmental radiochemistry. If these are not done, the educational problems in nuclear chemistry could not be correctly investigated and the remedies could not be correctly determined.

## Keywords

Nuclear Chemistry, Radiochemistry, Radiation Chemistry, Radiopharmaceutical Chemistry, Undergraduate Education, Universities

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## 1. Introduction

An overview of the undergraduate chemistry programs of different universities across the world shows clearly that nuclear chemistry education doesn't have a permanent status in chemistry curricula like classical sub-branches of chemistry which means like organic, inorganic, analytical, physical, and biochemistry, and this verifies the existence of serious educational problems in nuclear chemistry across the world. The challenges faced by professionals in this field have been voiced at different meetings and scientific platforms and a number of works and reports were appeared [1] [2] [3] [4] [5]. In parallel of these, in this examination study, the present status of nuclear chemistry education in different universities and countries was examined and evaluated.

As it is well known, several worldwide ranking systems for universities are operated and top world universities are scored [6] [7]. Surely, these ranking and scoring lists may be discussable; but, the universities that have high ranking scores and find places in the top levels of these lists are, in general, well known, prestigious, favored and successful universities, and the universities are in competition to climb to the top levels in these lists. For the examination of the present status of nuclear chemistry education in different universities and countries, undergraduate chemistry programs of top 50 universities and the number one university in 50 different countries were carefully investigated. In addition, about 35 universities were chosen to be remarkable examples for nuclear chemistry education in different countries.

## 2. The Position of Nuclear Chemistry in Chemistry Education

Before starting the evaluation of the status of nuclear chemistry education, first of all, nuclear chemistry should be correctly defined and its place in chemistry education should be correctly determined. If it is not done, the educational problems in nuclear chemistry could not be correctly investigated and the remedies could not be correctly determined.

### Where Is the Place of Nuclear Chemistry in Chemistry Main Branch and What Is the Exact Definition of Nuclear Chemistry?

As it can easily be observed from the chemistry programs of the majority of chemistry departments in different universities worldwide, the classical branches of chemistry generally consist of organic, inorganic, analytical, physical, and biochemistry sub-branches as represented in **Figure 1**.

This reflects surely the historical development of chemistry; but, rapid development of chemical knowledge and its applications in science and technology have created too many fine subbranches in about last 50 years such as electrochemistry, polymer chemistry, medicinal chemistry, geochemistry, coordination chemistry, computational chemistry, environmental chemistry, quantum chemistry, theoretical chemistry, pharmaceutical chemistry, photochemistry, solid-state chemistry, etc. Of course, radiochemistry, radiation chemistry, radioanalytical chemistry, radiopharmaceutical chemistry, etc. should also be included in this list as other fine sub-branches of chemistry.

Here, it should be asked: "Where is the place of nuclear chemistry in the main

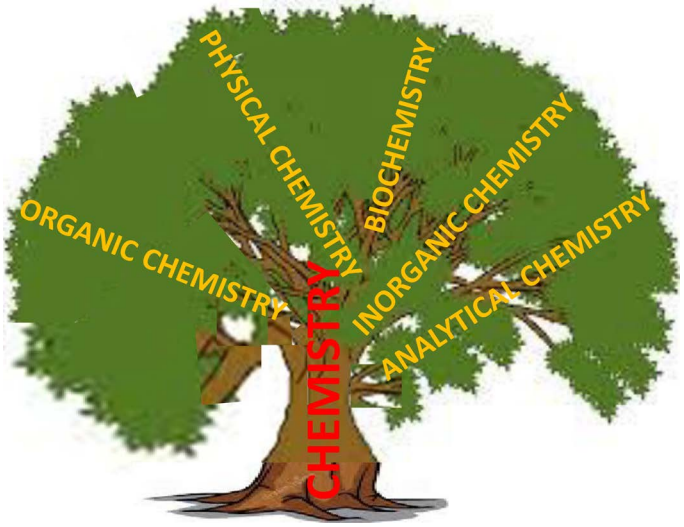


**Figure 1.** The chemistry branch and its classical sub-branches in natural sciences.

branch of Chemistry?" and a correct answer for this very critical question for nuclear chemistry must find. First of all, we must understand, why the main classical chemistry branches are considered to consist of five branches that is organic, inorganic, analytical, physical, and biochemistry? When basic methods and the main considerations of these sub-branches of chemistry are carefully examined, the answer to this question can easily be understood. It mean that the basic methods and the main considerations of these sub-branches of chemistry are completely different from each other; but, in spite of the appearance of new fine sub-branches that were indicated above, the main sub-branches of chemistry did not change. Why? Because, the basic methods and main considerations used by these new fine sub-branches can be collected, in principle, under these five sub-branches of chemistry.

As is well known, with the discovery of a radioactive material by Henry Becquerel in 1896 and then, some others by Marie Curie, and also nuclear radiation, chemistry envisaged using new methods and considerations for studying the chemistry of radioactive materials and related nuclear radiation. Following this discovery, the term "Radiochemistry" was introduced as the first term related to the chemistry of radioactive materials in the chemistry literature.

In the following years, according to the new applications of radioactive materials and nuclear radiation in different fields of science and technology, additional new terms were introduced into the literature of chemistry such as nuclear chemistry, radiation chemistry, radioanalytical chemistry, radiopharmaceutical chemistry, nuclear and radiochemistry, etc. Now, it should be interrogated, if all these fine sub-branches of chemistry that are related to the chemistry of radioactive materials and nuclear radiation, can be collected under the five classical sub-branches of chemistry, like all other fine sub-branches indicated above, or not? The answer is simple and clear: No! Because, all these fine sub-branches have completely different methods and considerations for studying of the chemistry related to radioactive materials and nuclear radiation than that of the five classical sub-branches of chemistry.

For this reason, all these fine sub-branches of chemistry that are related to the

chemistry of radioactive materials and nuclear radiation should be collected under a special category and introduced into the main sub-branches of chemistry. What term can be used as an umbrella for all of these fine sub-branches of chemistry related to radioactive materials and nuclear radiation?

Looking at the famous text books published in approximately the last 60 years in this field of chemistry, which is related to the chemistry of radioactive materials and nuclear radiation and their applications in science and technology will surely help to find the term as umbrella.

In 1949 a textbook was published by Gerhard Friedlander and Joseph W. Kennedy with the title "*Introduction to Radiochemistry*" [8].

In 1957, another textbook in French was published by Moise Häissinsky, a French author, with the title "*La Chimie Nucléaire et ses Applications*", including all knowledge related to radioactive materials and nuclear radiation up that date. This book was later published in English with the title "Nuclear Chemistry and its Applications" in 1964 [9].

In 1966, Gerhard Friedlander and Joseph W. Kennedy have published the second edition of their textbook that include the name of Julian Malcolm Miller as the third author with the title "*Nuclear and Radiochemistry*", including similarly updated knowledge in this field [10]. Of course, this title resulted in an important question: Are nuclear chemistry and radiochemistry different fine sub-branches of chemistry? Also, does it cover other fine sub-branches such as radiation chemistry, radioanalytical chemistry, radiopharmaceutical chemistry, etc, or not? It must find correct answers to these questions.

In 1980, Gregory Choppin and Jan Rydberg published their famous textbook with the title "*Nuclear Chemistry* (*Theory and Applications*)" that included nearly all topics related to the fine sub-branches mentioned above, which are related to the chemistry of radioactive materials and nuclear radiation and their scientific and technological applications as specific chapters and/or sub-chapters [11]. It should also be noted that these authors wrote in the preface of their textbook, seemingly to obscure the confusion between the main types of this branch of chemistry that "*There is no universally accepted definition for the term nuclear chemistry*". At the same time, it is interesting that later editions of this textbook appeared with the title "*Radiochemistry and Nuclear Chemistry*" without considerably changing the contents of the main topics in the first edition [12] [13] [14].

In 2003, A handbook series consisted of five volumes published in English by Atilla Vértes, Sándor Nagy, and Zoltán Klencsár with the title "*Nuclear Chemistry*" and each volume specified different topics. The sixth volume was later added to this series [15].

Some other textbooks published with different titles in this period of time from the 1960's to today are listed in **Table 1**. As it is seen from this table, the majority of these textbooks are titled as "Nuclear Chemistry" and a few books have "Radiochemistry" titles, while only a book has the title "Nuclear and Radiochemistry".

It is also interesting to note that a journal with the title of "*Radioanalytical Chemistry*" was founded in January 1968 by the famous Hungarian scientist, Tibor Braun. Surely, this was a great step for analytical chemists who work with radioactive

**Table 1.** Some other textbooks published with different titles in this field of chemistry in the period of time from the 1960's to today.

| |
|---|
| **Experimental Nuclear Chemistry** |
| Gregory R. Choppin, Prentice-Hall, 1961, 226 Pages. |
| **Nuclear Chemistry** |
| Eugene Eichler, G. Davis O'Kelley Interscience Publishers, 1963, 202 Pages. |
| **Basic Concepts of Nuclear Chemistry** |
| Ralph T. Overman Reinhold, Pub. Corp., 1963, 116 Pages. |
| **Nuclear Chemistry and its Applications** |
| M. Haïssinsky, Addison-Wesley Pub. Co., 1964, 834 Pages. |
| **Nuclear Chemistry** |
| Marc Lefort Van Nostrand, 1968, 531 Pages. |
| **Nuclear Chemistry** |
| Leo Yaffe, Academic Press, 1968, 409 Pages. |
| **Prenciples of Radiochemistry** |
| Herbert Alwyn, Cochrane McKay, Butterworths, 1971, 550 Pages. |
| **Enstrumentation in Applied Nuclear Chemistry** |
| Jan Krugers, Joel B. Ayers, Plenum Press, 1973, 383 Pages. |
| **Radiochemistry–Theory and Experiment** |
| Thomas Arthur, Hardy Peacocke, Wykeham Publications, 1978, 274 Pages. |
| **Radiochemistry** |
| Cornelius Keller, Ellis Horwood, 1988, 208 Pages. |
| **Essentials of Nuclear Chemistry** |
| Hari Jeevan Arnikar, New Age International,1995, 1987, 343 Pages. |
| **Radiochemistry and Nuclear Methods of Analysis** |
| William D. Ehmann, Diane E. Vance, Wiley, 1991, 531 Pages. |
| **Nuclear Chemistry** |
| Oldřich Navrátil, E. Horwood, 1992, 389 Pages. |
| **Fundementals of Radiochemistry** |
| Jean Pierre Adloff, Robert Guillaumont, CRC Press, 1993, 414 Pages. |
| **An Introduction to Nuclear Chemistry** |
| M. Satake, Discovery Publishing House, 1995, 232 Pages. |
| **Modern Nuclear Chemistry** |
| Walter D. Loveland, David J. Morrissey, Glenn T. Seaborg, Willey, 2005, 704 Pages. |
| **Nuclear Chemistry** |
| M Sharon, CRC Press, 2009, 230 Pages. |
| **Nuclear Chemistry (New Research)** |
| Axel N. Koskinen, Nova Science Publishers, 2009, 280 Pages. |
| **Nuclear and Radiochemistry** |
| Jens-Volker Kratz, Karl Heinrich Lieser, John Wiley & Sons, 2013, 202 Pages. |

materials and nuclear radiation to obtain a good platform for publication of their research reports. According to the rapid development of this branch of chemistry, the title of that journal was updated in 1984, 16 years after the founding, to the "*Journal of Radioanalytical and Nuclear Chemistry*". Of course, this title has created a similar question: Are radioanalytical chemistry and nuclear chemistry different fine sub-branches of chemistry, or not?

In this period of time, also new terms appeared and are used in this field of chemistry

such as radiation chemistry, radiopharmaceutical chemistry, environmental radiochemistry, etc.

In 1999, the organizers of the International Nuclear Chemistry Forum, distributed an inquiry to many scientists who were directly or indirectly related to the chemistry of nuclear materials and nuclear radiation and their applications in which the following question was included: "*Do you consider that nuclear chemistry and radiochemistry are different fields*?" Out of about 250 ansvers 35% answered *Yes* and 65% answered N*o*.

This story clearly verifies that a confusion of terminology or at least, turbulence exist in this branch of chemistry about the use of these terms.

Briefly, starting from the textbooks of Moise Häissinsky, the first edition of Gregory Choppin *et al*., the six volumes of Atilla Vértes *et al*., and others, nuclear chemistry should be considered as the title of the sixth main sub-branch of chemistry as is considered in the web site given as ref. [16] that covers all chemical studies related to radioactive materials and nuclear radiation including fine sub-branches such as radiochemistry, radiation chemistry, radioanalytical chemistry, radiopharmaceutical chemistry, environmental radiochemistry, and others as represented in Figure 2 and Figure 3.

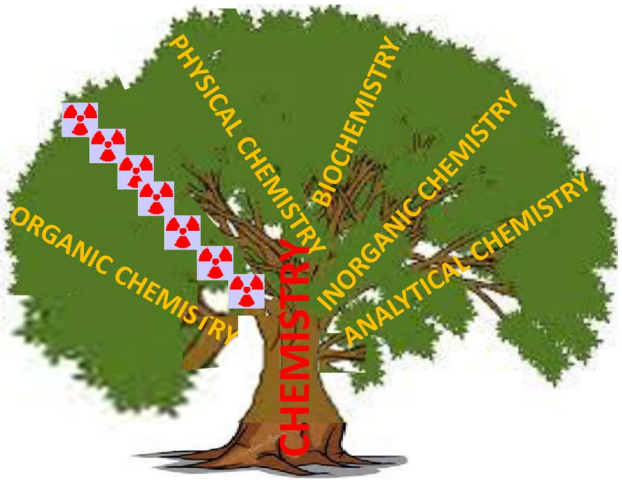


Figure 2. The place of nuclear chemistry and in the chemistry branch.

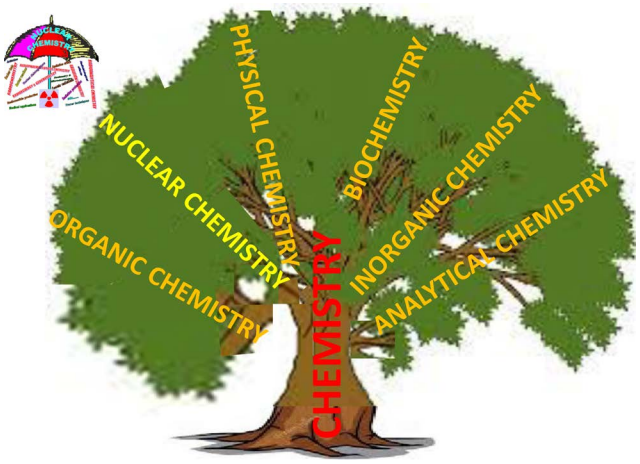


Figure 3. Nuclear chemistry its main sub-branches.

## 3. Nuclear Chemistry Education in Different Universities and Countries

The international ranking system for universities as the success reference of universities was first considered for examination of the status of nuclear chemistry education across the world.

### 3.1. Chemistry Programs of Top 50 Universities in the World

The chemistry programs af the top 50 universities in the list of world ranking system for 2014 in the category of physical sciences were carefully browsed using their internet web addresses and their last updated undergraduate chemistry programs were examined. During this browsing, all courses with whatever title, but related to the chemistry of radioactive materials and nuclear radiation and its applications were searched.

The top 50 universities and some related courses observed are listed in Table 2. As is seen from this table, the searching result was a big disappointment for this branch of chemistry. Because only, a few universities have some courses with different titles based on nuclear phenomena or which study nuclear radiation or its applications; others have nothing! Surely, this is a very problematical situation and the reasons for this very important omission need to be very carefully evaluated.

But, it should obviously be outlined that this is only valid for chemistry programs. If not, some of these universities have several courses related to this branch of chemistry in other educational programs such as in the programs of nuclear engineering, nuclear medicine, radiopharmaceutical applications, etc. Also, universities have some courses in this field in their MsD and PhD programs.

### 3.2. Chemistry Programs of No 1 Universities in 50 Different Countries

Another examination was carried out using another criterion for universities. According to this criterion, no 1 universities in 50 different countries were considered for examination. Of course, the no 1 university of each country mean that these universities have the highest national ranking scores in their home counties. This is also another way to evaluate the universities for their successfulness.

The chemistry programs of no 1 universities in 50 different countries were also carefully browsed. Table 3 shows these no 1 universities in 50 different countries and as its seen, the general situation is not considerably different than that of the 50 top universities. Only, some universities have some courses with different titles. But still, the majority of these universities have nothing on this matter.

### 3.3. Universities Having Remarkable Courses in Nuclear Chemistry

In spite of this negative situation for education in nuclear chemistry in chemistry programs either in top 50 universities in the world or no 1 universities in 50 different countries, some universities that are far from the top of these lists and have low international or national ranking scores, do run considerably remarkable, sometimes intensive courses related to nuclear chemistry and/or its applications. As examples of these types of universities, about 35 universities were determined from different countries.

As it can be seen from the list given in Table 4, these universities have different

Table 2. According to the universities ranking system for physical sciences, the list of top 50 universities, their countries and world scores. (This ranking list was copied from the following web site: http://www.timeshighereducation.co.uk/world-university-rankings/2013-14/subject-ranking/subject/physicalsciences).

| NO. | UNIVERSITY | COUNTRY | WORLD SCORE | COURSES |
|---|---|---|---|---|
| 1 | California Institute of Technology (Caltech) | USA | 92.0 | Ge/Ch 127 Nuclear Chemistry |
| 2 | Massachusetts Institute of Technology (MIT) | USA | 91.0 | |
| 2 | Princeton University | USA | 91.0 | |
| 4 | Harvard University | USA | 90.2 | |
| 5 | University of California, Berkeley | USA | 89.9 | CHEM 143 Nuclear Chem.<br>CHEM 146 Chemical Methods in Nuclear Technology |
| 5 | Stanford University | USA | 89.9 | |
| 7 | University of Cambridge | UK | 88.8 | |
| 8 | University of Oxford | UK | 87.3 | |
| 9 | University of California, Los Angeles (UCLA) | USA | 85.1 | |
| 10 | Universityof Chicago | USA | 84.9 | |
| 11 | Yale University | USA | 83.6 | CHEM 437b Chemistry of Isotopes<br>CHEM 440a Molecules and Radiation I<br>CHEM 442b Molecules and Radiation II |
| 12 | ETH Zürich –Swiss Federal Institute of Technology Zürich | Switzerland | 83.2 | 535-0210-00L Radiopharma- ceutical Chemistry |
| 13 | Imperial College London | UK | 82.5 | |
| 14 | Columbia University | | 81.0 | |
| 15 | Cornell University | USA | 80.7 | |
| 16 | The University of Tokyo | Japan | 73.5 | |
| 17 | Universityof Toronto | Canada | 71.7 | |
| 18 | Universityof Washington | USA | 71.5 | CHEM 410 Radiochemistry Lab.<br>CHEM 418 Nuclear Chemistry |
| 19 | Ludwig-Maximilians-Universität München | Germany | 71.3 | |
| 20 | Universityof California, SantaBarbara | USA | 71.1 | |
| 21 | Universityof Texasat Austin | UK | 71.0 | |
| 22 | University of Michigan | USA | 70.0 | |
| 23 | École Polytechnique Fédérale de Lausanne | Switzerland | 69.4 | |
| 24 | University of Melbourne | Australia | 68.9 | |
| 25 | Université Pierre et Marie Curie | France | 67.6 | |
| 26 | University of British Columbia | Canada | 67.0 | CHEM 417 Nuclear Chemistry and Radiochemistry |
| 27 | University of Wisconsin-Madison | USA | 66.6 | |
| 27 | Northwestern University | USA | 66.6 | |
| 29 | École Normale Supérieure | France | 65.8 | |
| 29 | AustralianNationalUniversity | Australia | 65.8 | |
| 31 | Georg-August-UniversitätGöttingen | Germany | 65.5 | |

**Continued**

| | | | | |
|---|---|---|---|---|
| 32 | Peking University | China | 65.3 | Radiochemistry Radiation chemistry |
| 33 | University of Illinois at Urbana Champaign | USA | 65.0 | |
| 34 | Rice University | Australia | 64.7 | |
| 35 | Brown University | Canada | 64.6 | |
| 36 | Kyoto University | Japan | 64.3 | |
| 37 | University of Edinburgh | UK | 61.6 | |
| 38 | Pennsylvania State University | USA | 61.5 | |
| 38 | École Polytechnique | France | 61.5 | |
| 40 | Carnegie Mellon University | USA | 61.4 | |
| 41 | National University of Singapore (NUS) | Singapore | 61.2 | |
| 42 | Technische Universität München | Germany | 61.0 | Radiochemistry |
| 43 | Universität Heidelberg | Germany | 60.5 | |
| 44 | University of Colorado Boulder | USA | 59.9 | |
| 45 | University of California, San Diego | USA | 59.6 | |
| 47 | Georgia Institute of Technology (Georgia Tech) | USA | 59.4 | |
| 48 | Stockholm University | Sweden | 58.1 | |
| 49 | University of Minnesota | USA | 58.0 | |
| 50 | Universityof Manchester | UK | 57.9 | |

Table 3. The list of no 1 universities in 50 different countries, their world scores and related courses. (The list of No.1 universities in different countries was copied from the following web site: http://www.topuniversities.com).

| NO. | UNIVERSITY | COUNTRY | WORLD ORDER | COURSES |
|---|---|---|---|---|
| 1 | Massachusetts Institute of Technology (MIT) | USA | 5th | |
| 2 | University of Cambridge | UK | 7th | |
| 3 | ETH Zurich (Swiss Federal Institute of Technology) | Switzerland | 14th | |
| 4 | National University of Singapore (NUS) | Singapore | 26th | |
| 5 | McGill University | Canada | 35th | |
| 6 | The Hong Kong University of Science and Techn. | Hong Kong | 43th | |
| 7 | Seoul National University | South Korea | 44th | |
| 8 | Peking University | China | 45th | Radiochemistry, radiation chemistry |
| 9 | Australian National University | Australia | 48th | |
| 10 | KU Leuven | Belgium | 61th | |
| 11 | Ecole Normale Supérieure, Paris | France | 65th | |
| 12 | Technische Universität München | Germany | 87th | Radiochemistry |
| 13 | University of Helsinki | Finland | 100th | |
| 14 | Lund University | Sweden | 123rd | |

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| | | | | |
|---|---|---|---|---|
| 15 | University of Cape Town | South Africa | 126th | |
| 16 | National Taiwan University (NTU) | Taiwan | 142nd | |
| 17 | University of Amsterdam | Netherland | 144th | |
| 18 | University of Copenhagen | Denmark | 150th | |
| 19 | University of Vienna | Austria | 170th | |
| 20 | University of Oslo | Norway | 185th | |
| 21 | Hebrew University of Jerusalem | Israel | 191th | |
| 22 | Universidad de Buenos Aires | Argentina | >200th | |
| 23 | Universidade de São Paulo (USP) | Brazil | >200th | |
| 24 | Pontificia Universidad Católica de Chile | Chile | >200th | |
| 25 | Universidad de Los Andes Colombia | Colombia | >200th | |
| 26 | Charles University | Czech Republic | >200th | |
| 27 | American University in Cairo | Egypt | >200th | |
| 28 | Aristotle University of Thessaloniki | Greece | >200th | |
| 29 | Indian Institute of Technology Delhi (IITD) | India | >200th | |
| 30 | University of Indonesia | Indonesia | >200th | |
| 31 | Trinity College Dublin | Ireland | >200th | Nuclear and Medicinal Inorganic Chemistry |
| 32 | University of Bologna | Italy | >200th | |
| 33 | The University of Tokyo | Japan | >200th | |
| 34 | L.N. Gumilyov Eurasian National University | Kazakhstan | >200th | |
| 35 | American University of Beirut (AUB) | Lebanon | >200th | |
| 36 | Universiti Malaya (UM) | Malaysia | >200th | |
| 37 | Universidad Nacional Autónoma de México (UNAM) | Mexico | >200th | |
| 38 | The University of Auckland | New Zeland | >200th | |
| 39 | Sultan Qaboos University | Oman | >200th | |
| 40 | National University of Sciences and Technology (NUST) Islamabad | Pakistan | >200th | |
| 41 | University of the Philippines | Philippines | >200th | Radioisotope Tech. (in Analy. Chem.), Nuclear Chemistry (in Inorganic Chem.) |
| 42 | Jagiellonian University | Poland | >200th | |
| 43 | University of Coimbra | Portugal | >200th | |
| 44 | Lomonosov Moscow State University | Russia | >200th | Department of Radiochemistry |
| 45 | King Saud University | Saudi Arabia | >200th | |
| 46 | Universitat Autónoma de Barcelona | Spain | >200th | |
| 47 | Chulalongkorn University | Thailand | >200th | |
| 48 | Bilkent University | Turkey | >200th | |
| 49 | United Arab Emirates University | United Arab Emirate | >200th | |
| 50 | Universidad ORT Uruguay | Uruguay | >200th | |

Table 4. List of universities that are far from the top of the lists given in Table 1 and Table 2 and have low international or national ranking scores, do run considerably remarkable, sometimes intensive courses related to nuclear chemistry and/or its applications, as examples of these types of universities.

| UNIVERSITY | COUNTRY | WORLD ORDER & RANKING SCORE | COURSES |
|---|---|---|---|
| University of Kentucky<br>College of Arts and Sciences<br>Department of Chemistry | USA | >400th | CHE 520: Radiochemistry<br>CHE 521: Radiochemistry Lab.<br>CHE 616: Nuclear Chemistry |
| Tennessee Tech. University<br>Department of Chemistry | USA | >400th | CHEM 4310/5310<br>Nuclear and Radiochemistry |
| Missouri University College of Arts and Science<br>Department of Chemistry | USA | >400th | National Nuclear Chemistry<br>Summer Schools |
| Delft University of Technology<br>Faculty of Applied Sciences | Netherland | 69th<br>(59.1) | CH3771: Nuclear Chemistry |
| Universty of Maryland<br>Department of Chemistry & Biochemistry | USA | >400th | CHEM705: Nuclear Chemistry |
| Defance Academy of the United Kingdom | UK | | (NCC) - ME844N<br>Nuclear Chemistry |
| Indiana University<br>Department of Chemistry | USA | 132nd<br>(50.1) | C460: Nuclear Chemistry |
| Berkley<br>University of California | USA | >400th | CHEM 143: Nuclear Chemistry<br>CHEM 243: Advanced Nuclear Structure and Reactions |
| University of Nord Carolina | USA | >400th | 073 First-Year Seminar: The Broad Scope of Nuclear Chemistry<br>(From Atomic Bombs to Cancer Treatments) |
| KTH Royal Institute of Technology | Sweden | 117th<br>(51.6) | KD2080: Nuclear Chemistry |
| Michigan State University<br>Department of Chemistry | USA | 83rd<br>(55.9) | CEM 485: Modern Nuclear Chemistry<br>CEM 985: Selected Topics in Nuclear Chemistry |
| Manchester University<br>School of Chemistry | UK | >400th | CHEM40311: Radiochemistry and Nuclear Chemistry |
| Chalmers Institute of Technology | Sweden | >400th | Nuclear Chemistry |
| Jomo Kenyatta University of Agriculture and Technology | Kenya | >400th | SCH 2203: Nuclear Chemistry and Radiochemistry |
| Mount Royal University<br>Fac. of Science & Tech.<br>Department of Chemistry | Canada | >400th | CHEM 3801: Nuclear Chemistry |
| University of British Colombia<br>Faculty of Science Department of Chemistry | Canada | >400th | Nuclear and Radiochemistry |
| Rockhurst University<br>Department of Chemistry | USA | >400th | CH 3650: Nuclear Chemistry |
| University of Bergen<br>Department of Chemistry | Norway | 201th - 225th | KJEM260: Radiochemistry and Radioactivity |
| University of Massachusetts Lowell<br>Department of Chemistry | USA | >400th | 95.441: Radiochemistry |
| University of Kentucky<br>Department of Chemistry | USA | >400th | CHE 520: Radiochemistry<br>CHE 521: Radiochemistry Lab.<br>CHE 616: Nuclear Chemistry |
| Uppsala Universirty<br>Department of Chemistry | Sweden | >400th | UU-49001: Nuclide Production and Radiochemistry |

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| | | | |
|---|---|---|---|
| Norvegian University of Life Scences | Norway | >400th | KJM350 Radiation and Radiochemistry |
| University of Utah<br>Department of Chemistry | USA | 143rd<br>(49.1) | 3200: Radiochemistry I |
| Washington University in St. Louis<br>Department of Chemistry | USA | >400 | Chemistry 536: Radiochemistry for the Life Sciences |
| Delft University of Technology<br>Fac. Appl. Sciences | Nether-<br>land | 69th<br>(59.1) | CH3771: Nuclear Chemistry |
| California State University Northridge<br>Dept.of Chem.& Biochem. | USA | >400th | Chem 481: Radiochemistry |
| James Madson University<br>Department of Chemistry & Biochemistry | USA | >400th | CHEM 450: Nuclear and Radiation Chemistry<br>CHEM 450L: Laboratory for Nuclear and Radiation Chemistry |
| University of Oslo<br>Department of Chemistry | Norway | 185th<br>(43.3) | FYS-KJM4710: Radiation and Radiation Dosimetry<br>KJM5901: Radiochemical Methods<br>KJM5950:Radiopharmaceutical Chemistry |
| University of Nairobi<br>Department of Chemistry | Kenya | >400th | SCH 408: Nuclear and Radiation Chemistry |
| Western University | Canada | 22nd<br>(77.1) | Chem 4404: Radiation and Nuclear Systems Chemistry |
| University of Washington<br>Depatment of Chemistry | USA | 25th<br>(73.4) | Chemistry 418: Nuclear Chemistry and Radiochemistry<br>Chemistry 410: Nuclear Chemistry Laboratory |
| Western University Department of Chemistrty | Canada | >400th | Chem 4404: Radiation and Nuclear Systems Chemistry |
| Royal Institute of Technology | Sweden | >400th | Nuclear Chemistry |
| University of Texas<br>Chemistry Program | USA | 188th<br>(45.2) | CHEM 4389: Modern Nuclear Chemistry |
| St. Kliment Ohridsky University of Sofia<br>Nuclear Chemistry<br>BS Degree Program | Bulgaria | >400th | GOOD EXAMPLE |
| Czech Technical University<br>Department of Nuclear Chemistrty | Czech Rep. | >400th | GOOD EXAMPLE |

courses under different titles; but, the majority of the course titles are nuclear chemistry. Of course, this is a good statement for nuclear chemistry education. In this list you see two universities that were noted as "Good example" at the last lines of the Table 3. In case of establishing a nuclear chemistry ranking system for universities, these two universities should be recognized as the top universities in the world according to the nuclear chemistry ranking system. One of these two universities is Czech Technical University in the Czech Republic has a Department of Nuclear Chemistry which means that nuclear chemistry is as a basic field of education, offering many courses related to this field as shown in Table 5.

Another good example is the Faculty of Chemistry in St. Kliment Ohridsky University of Sofia in Bulgaria. This faculty has a Bachelor Degree program for nuclear chemistry, which includes many courses related to this field as shown in Table 6.

The details of an undergraduate nuclear chemistry program at the Department of Chemistry, Ege University, Faculty of Science, in Turkey was published in 2009 with the title "An ideal teaching program of nuclear chemistry in the undergraduate chemistry curriculum". Surely, this was also a good example for education in nuclear

**Table 5.** Czech Technical University Department of Nuclear Chemistry, as one of good examples for education in nuclear chemistry (This information is copied from the following web site: http://www.jaderna-chemie.cz/?predmet=prehled_en).

**CZECH TECHNICAL UNIVERSITY DEPARTMENT OF NUCLEAR CHEMISTRTY Courses provided by this Department:**

Analytical Calculations and Chemometry Principals

Aplication of Radionuclides I

Aplication of Radionuclides II

Application of Radiation Methods

Bachelor's thesis I

Bachelor's thesis II

Compile a Search I

Compile a Search II

Determination of Radionuclides in the Environment

Environmental Chemistry and Radioecology

Excursion I

Excursion II

General Chemistry

General Chemistry I

General Chemistry II

General Chemistry Calculations

Chemistry of Radioactive Elements

Instrumental Methods I

Instrumental Methods II

Introduction to Nuclear Chemistry

Introduction to Photochemistry and Photobiology

Ionising Radiation Detection

Laboratory Practice in the Instrumental Methods

Master's Thesis I

Master's Thesis II

Measurement and Data Handling

Modelling of the Migration Processes in the Environment

Nuclear chemistry I

Nuclear chemistry II

Nuclear Materials Technology

Nuclear Power Plants Design and Operation

Numerical Simulation of Complex Environmental Processes

Physical Chemistry 1

Physical Chemistry 2

Physical Chemistry 3

Physical Chemistry 4

Physical Chemistry 5

Practical Exercises in Radiation Methods in Biology and Medicine

Practical Exercises in Radiation Chemistry

**Continued**

| |
|---|
| Practical Exercises in Detection of Ionizing Radiation |
| Practical Exercises in Microbiology |
| Practical Exercises in Nuclear Chemistry |
| Practical Exercises in Radioanalytical Methods |
| Practical Exercises in Radiochemistry Techniques |
| Practical Exercises in Separation Methods |
| Protection of the Environment |
| Radiation Chemistry |
| Radiation Methods in Biology and Medicine |
| Radioanalytical Methods |
| Radionuclide Production |
| Radiopharmaceuticals I |
| Radiopharmaceuticals II |
| Research Project I |
| Research Project II |
| Seminar I |
| Seminar II |
| Separation Methods in Nuclear Chemistry I |
| Separation Methods in Nuclear Chemistry II |
| The Chemistry of Operation of Nuclear Power Plants |
| The Technology of the Fuel Cycles of Nuclear Power Stations |
| The Theory of the Electromagnetic Field and Wave Motion |
| Trace Radiochemistry |
| Waste Analysis |
| Waste Management and Treatment |

**Table 6.** St. Kliment Ohridsky University of Sofia in Bulgaria Nuclear Chemistry Bachelor Degree Program in the Faculty of Chemistry as one of good examples for education in nuclear chemistry. (This information is copied from the following web site: http://www.chem.uni-sofia.bg/BachNuclChem_en.htm).

| |
|---|
| **ST. KLIMENT OHRIDSKY UNIVERSITY OF SOFIA IN BULGARY** |
| **FACULTY OF CHEMISTRY** |
| **Nuclear Chemistry Bachelor Degree Program** |
| **Related courses provided by this program:** |
| Nuclear and Radiochemistry I |
| Nuclear and Radiochemistry II |
| Radiation Protection |
| Radioanalitycal Chemistry |
| Chemistry of the Nuclear Fuel Cycle and of Nuclear Reactions |
| Production of Radioactive Isotopes and Labeled Compounds |
| Radioactive Wastes |
| Nuclear safety, Risk Analysis and Risk Informed Decision Making |
| Fundamental of Radiobiology |

chemistry [17].

## 4. Conclusions

This short overview of nuclear chemistry education programs has reached some important conclusions:

1) The umbrella role of nuclear chemistry should be strongly supported everywhere;
2) Nuclear chemistry should be emphasized as the sixth main sub-branch of chemistry;
3) The overview of nuclear chemistry education in universities across the world has clearly indicated that nuclear chemistry education has not yet achieved a classical status in chemistry curricula worldwide like organic, analytical, inorganic, physical, and biochemistry; but, all undergraduate chemistry programs of universities across the world should cover at least one nuclear chemistry course with some laboratory experiments, like in the case of other main sub-branches of chemistry;
4) It is evident that the majority of active chemistry staff surely does not have enough knowledge of today's importance of nuclear chemistry and its scientific and technological applications, which results in a huge lack of nuclear chemistry education in the formulation of chemistry curricula;
5) This present status prevents the education of new staffs in nuclear chemistry and so, this creates a vicious circle for the subject;
6) The universities having remarkable nuclear chemistry courses which were identified can be attributed to the personal efforts of some well-educated staff in nuclear chemistry and this does not guarantee that the same status will continue in the future in their universities after their retirements and for this reason, it will be evident that as notified by Gregory Choppin "The need for radiochemists (he meant surely nuclear chemists) must grow; but in most countries, including the US, there will soon be no professors to train them!";
7) Today's active nuclear chemistry staff should understand that they have been charged with a very important mission for the future status of nuclear chemistry and that they need to be much more active and try to help other chemistry staff in their universities to understand that nuclear chemistry education should have a permanent place in chemistry curricula without depending on temporary personnel efforts and activities;
8) Nuclear chemistry staff should communicate with all national or international scientific organizations to spread more understanding of the important role of nuclear chemistry in scientific and technological applications required for future human life;
9) The number of civil national and international organizations such as the International Nuclear Chemistry Socciety (INCS) and the Radiochemistry Society in the US, etc. should be increased;
10) A master program for nuclear chemistry in undergraduate education needs to be formulated and it should be recommended for introduction into all chemistry curricula in various universities across the world. This would help to create more interest in the field of nuclear chemistry among the younger generation.

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