Iran’s Lithium-6 Research: Background and Overview

An Analysis using the Open Source Scientific Literature

Part I

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Revision 1.1

Introduction: The metal lithium, isotopes and compounds play an important role in modern society. Medical compounds, alloys, nuclear dual-use applications in both civilian and military applications are all important uses for lithium and its isotopes.

The purpose of this report is to focus on the role lithium and its isotopes have played and continue to play in Iranian dual-use civilian and military programs. The open source scientific literature was searched to provide detailed material on Iranian research in this area.

The report is divided into three volumes.

Part I contains the following sections:

Section I will focus on the early stages of research done at foreign universities into the nuclear applications of lithium. PhD thesis obtained downloaded from the universities served as the beginning of research into this area, followed by conference papers, journal articles, and documents/reports.

Section II will focus on mineral resources available to Iran in the areas of brines, mineral deposits and ocean water extraction. This section will also focus on the purification of these resources into high-purity lithium compounds.

Section III will focus on the separation of lithium isotopes using the amalgam electrolysis method, laser isotope separation and the use of crown ethers such as 18-crown-6.

Section IV will focus on analytical techniques used for the determination of lithium isotope abundances.

Section V will focus of the synthesis and material properties of lithium compounds for use in the tritium breeding program and tritium production in the Tehran Research Reactor.

Section VI will focus on actual tritium production experiments carried out in the Tehran Research Reactor and will also look at the upgrading research being done at this reactor to improve isotope production.

Section VII will focus on the computer simulations of tritium breeding compounds such as lithium silicates and titanates in the ITER/DEMO fusion reactors.

Part II of this report focuses on proliferation and weaponization issues relating to Iranian Li6/tritium research its compounds and possible proliferation aspects of nuclear fuel cycle research being carried out in Iran.

Lastly Part III is to be an updated version of the March 2021 Annotated Reference Guide.

Much has been written about Iran's nuclear device related research but little to no information has been published regarding Iran's Lithium-6 research.[1] The referenced list contains some of the most recent and more important reports written regarding Iran's nuclear activity.

The author's seven volume Iranian Dual-Use Science and Technology Bibliographies are the most comprehensive reference guide to Iranian open source scientific information and are available on the Federation of American Scientists website and researchgate.net.[2]

Detailed information on Iran's past nuclear weapons related research can be found in David Albright's numerous reports on the Iranian Nuclear Archives and his most recent book entitled "Iran's Perilous Pursuit of Nuclear Weapons".[3] This author was a member of the Good ISIS team that assisted in this research and analysis.

Section I:

British universities have played a historic role in training young researchers from many different countries. Iran is among one of those countries who sent their best and brightest students to study physics in the UK at universities such as the University of Birmingham.

One of the most important students to pursue and obtain his graduate degrees from the University of Birmingham is Rahim Koohi-Fayeth who is currently a professor at the Department of Physics, Ferdowsi University of Mashad.[(4)] While at the University of Birmingham he studied under Dr. Malcolm C. Scott. Financial support for his graduate studies was provided by the University of Ferdowsi, Mashhad and the Iranian Ministry of Science.

Koohi-Fayegh thesis was on the neutron spectrum measurement in a beryllium-lithium fluoride and is summarized as follows "The roles of integral experiments 1n providing cross checks of nuclear data and possible data adjustment are outlined. The need for sufficient knowledge of uncertainties in the integral and differential data is briefly discussed and the reasons for putting more effort on the data analysis technique previously used in this group are explained. The use of a miniature NE 213 neutron spectrometer system in absolute neutron flux measurements in a Be-LiF assembly has shown that the use of a more sophisticated neutron unfolding code than that previously employed in this group was necessary. The FERDOR neutron unfolding code has, therefore, been modified and employed for the neutron spectrometry purposes…..effort has been made to 1mprove the performance of the Monte Carlo calculations of such a response matrix.

The validity and reliability of the calculated response matrix is examined at one energy by comparing the calculated response function and a measured relative one. Some other checks of its validity are also made by comparing the FERDOR unfolded spectra with those of some other codes and measurements. It is concluded that our modified version of FERDOR gives acceptable results….Finally a representative set of Be transmission spectrum measurements and neutron flux measurements in a Be-LiF assembly are presented and comparisons with the calculations are made . No gross discrepancy is observed between measurements and calculations and therefore no gross discrepancy appears to exist in the present nuclear data of the elements concerned. It is, however, concluded that the minor discrepancies may possibly be attributed to minor errors ~n the current nuclear data, but further work is necessary before such a conclusion may be drawn with certainty."[5]

In simple terms his research focused on understanding the tritium production in a beryylium-lithium fluoride assembly shown in Figure 1. "Among the integral experiments carried out in this department the neutronic behaviour of some of the proposed blanket materials for controlled thermonuclear reactors (CTR) are being investigated. The process started in 1975 by developing a project in which the cross sections of n-Li reactions were to be evaluated. As a consequence of consideration of the materials which were easy to handle and economically available ~n large quantities, LiF was chosen as the material on which the first stage experiments were to be carried out. Consequently a LiF assembly was constructed (for details of the construction of the assembly see, for example, PERKINS 1978, or BREARLEY 1977).[6]

"This assembly consisted of an annular spherical shell with an outer diameter of 125 cm and an inner diameter of 50. 85 cm. The outside wall was made of plastic resin containing fi~ glass reinforcement, and of 6 mm wall was an aluminum sphere of 2.2 mm thickness. The inside shell was filled with LiF powder and vibrated to obtain uniform density and avoid formation of void in the LiF powder… At the end of the first-stage of this project at Birmingham the effect on the neutron flux and tritium production in the LiF assembly of the presence of other materials of CTR blankets such as beryllium was to be studied. Beryllium was chosen because a study of many conceptual CTR designs shows that not only have materials with high parasitic neutron cross section been avoided, but in providing for the creation of additional neutrons to supplement the loss through parasitic capture advantage 1s taken of the high energy neutrons present in the incident spectrum, by the use of materials with high (n,2n) cross section . Study of the CTR designs also shows that these materials occur near the first wall, i . e. n~~ ~ the source , before any appreciable moderation has taken place. The second-stage of the project was, therefore, devoted to measuring the flux 1n a modified assembly which included beryllium (in some form or another)".[7]

"The system (miniature spectrometer system) had been developed in the earlier stages of the project by PERKINS (1978) and has been fully described in his report. As mentioned earlier the detector consists of a 1 .305 cm diameter by 1.300 cm height cylindrical glass cell filled with NE 213 liquid scintillator. The cell is painted with NE 560 diffuse reflector paint and directly mounted on an RCA C31005C photomultiplier tube (direct in the sense that there 1s no light guide in the system) . The photomultiplier/scintillator assembly is enclosed by a 3.250 cm diameter thin walled (0.1 mm) stainless steel tube, with brass endcaps of 1 mm thickness."[7]

Koohi-Fayegh played an important role in developing "experimental techniques for 14 MeV neutron benchmark studies….The use of proton-recoil proportional and scintillation counters for measurements with 14 MeV neutrons is discussed. Details are given of investigations into their performance and that of the unfolding codes used, and examples of their application in LiF and LiF-Be integral assemblies are presented."[8]

Koohi-Fayegh also helped to develop a user's guide for the NE213 neutron spectroscopy system variants of which are used today to measure "characteristic events for neutron or gamma induced events" which has also been described in a series of journal articles and conference presentations. [9]

The ability to perform and analyze complex experiments such as these has played an important role in Iranian dual-use nuclear studies. In 1997 at the Iranian Physics Conference a paper was presented on "Experimental and computational analysis of neutron flux transmitted from spherical beryllium shells" Part of the abstract states "flux measurements were presented on experiments performed for a number of beryllium assemblies and calculations have been made using the complicated MCNP code. It has been shown that, in general, some discrepancies between the experimental and theory exist which could be caused by the uncertainties in the 9Be cross-sections."[10]

Further details of neutron spectrum measurements from 1-16 MeV in beryllium assemblies were given in a 2000 journal article. "This paper reports on the results of a series of 14 MeV neutron transmission measurements using an NE213 scintillation spectrometer with three different thicknesses of beryllium shells. The experimental results are then compared with MCNP Monte Carlo calculations using the ENDF/B-VI data set. For all three shells the experimental results lie above those calculated for neutron energies between 8 and 11 MeV, whilst between 1 and 4 MeV they lie below. It is concluded that there are continuing uncertainties in the data."[11]

The acknowledgements section of this journal article contains the following "Finally, one of us (R.K.-F.) would like to thank the University of Mashhad and the Iranian Ministry of Science for their financial support for the original programme, and the School of Physics and Astronomy, University of Birmingham, for assistance towards work undertaken in subsequent sabbatical leave periods".[12]

This journal article and other caught the attention of an unnamed diplomat who made the following comments. "The combination of the existence of a neutron initiator in a secret facility run by the Revolutionary Guard, making high- and not low-energy neutron experiments is a sufficient good indicator to a suspected military program".[13]

According to this diplomat, the neutron experiments are being conducted at a base of the elite Revolutionary Guard military on the outskirts of Tehran in a neutron generator in an isolated underground building. The base is near the Malek Ashtar Technology University where a team of six senior nuclear scientists and several research assistants do calculations from the data, the diplomat said. "Fast (high-energy) neutron experiments, involving 14 million electron volts, which are not slowed down by moderators and are performed in a classified facility, are designed for nuclear fission processes, that is nuclear bomb systems".[14]

One diplomat cited open-literature reports by Iranian nuclear scientists about work with high-energy neutrons and beryllium in universities in Birmingham, England and in Ferdowsi University in Mashhad, northeast Iran.[15] Its appears that after this news article appeared Koohi-Fayegh cut public ties with the University of Birmingham.

It is of interest to note that Israeli physicist Raphael Ofek's 1986 thesis was entitled "Intereactions of D-T neutrons in graphite and lithium blankets of fusion reactors: measurements and calculations"[16] Ofek studied the interaction of a collimated 14MeV neutron beam located at the center of lithium-7 cylinder of dimensions 88 cm. diameter and 88 c. height. The source of the lithium-7 used in this thesis was not reported although Israeli scientists had reported on the enrichment of the 6Li-isotope by electromigration back in 1961.[17] Ofek's thesis builds upon a 1981 thesis (neutron energy spectrum in graphite blankets of fusion reactors: measurements and calculations)done by Tsechanski.[18]

A 2002 Farsi language journal articles states for “the neutron spectrum from the reaction of deuteron on beryllium nuclei is measured. The energies of deuterons were 7,10, 13 and 15 MeVand these measurements are performed at 10, 30, and 50 degrees relative to the beam of the deuterons. The detector used is a 76 by 76 mm right circular cylinder of NE-213 liquid scintillator.” Among Koohi-Fayegh’s coauthors were Abbasi Davani who at that time was at the Institute of Applied Physics, University of Science and Technology and has been directly linked to Iran’s dual-use nuclear research program, Hossein Afarideh, Ghulam Reza Etaati.[19]

The 4.438 MeV gamma-ray to neutron emission ratio was measured and reported in a 2004 journal article. “Gamma-ray (γ-ray) spectra of a 1.49×10^{11} Bq ^{241}Am–^{9}Be source and background were measured using a 2 in×2 in, NaI(Tl) detector. Backgrounds due to the neutron interactions and energy deposition were calculated with MCNP4C.” Gholam Reza Etaati who was associated with the Institute of Applied Physics, University of Science and Technology is a coauthor of this journal article. In the acknowledgement of this article the financial and technical support of the Imam Hossein University were highly acknowledged. “The authors also wished to acknowledge the NPL (Birmingham University) for supporting the original project in Birmingham, in which initial detector design and software implementation and development took place.”[20]

Abbasi Davani is again acknowledged in a 2004 journal article that described a “Monte Carlo code, PHOTRACK, has been written to simulate the behavior of light photons in scintillation detectors, with and without light guides…The stimulus for the current work was the construction of by Hamidi of a miniature lithium glass scintillation detector for studying the epithermal neutron characteristics of the Birmingham BNCT facility.”[21] Hamidi’s Ph.D. thesis is a good example of civilian dual-use nuclear research performed at the University of Birmingham.[22]

Koohi-Fayegh coauthored another 2004 journal article (this is another example of research that has dual-use applications in the nuclear area) that stated “Neural network method was used for fast neutron spectra unfolding in spectrometry by threshold activation detectors. The input layer of the neural networks consisted of 11 neurons for the specific activities of neutron-induced nuclear reaction products, while the output layers were fast neutron spectra which had been subdivided into 6, 8, 10, 12, 15 and 20 energy bins. Neural network training was performed by 437 fast neutron spectra and corresponding threshold activation detector readings. The trained neural network have been applied for unfolding 50 spectra, which were not in training sets and the results were compared with real spectra and unfolded spectra by SANDII”.[23]

Further details of early Iranian nuclear research can be found in Appendix A of this volume.

Section II:

A 2016 Israeli review article focused on “Lithium in nature, application, methods of extraction”.[24] Of interest is the fact that the review gave estimates of Israel’s lithium deposits there is no mention of Iranian lithium deposits.

Of the several hypersaline water bodies present on the surface of the earth, the Urmia Lake is the one that has attracted and attracts the most attention. The Urmia Lake located at the NorthWest of Iran. The recovery of lithium as lithium aluminate from Urmia Lake was studied. Acoprecipitation method was utilized using aluminum salt as ($AlCl_3,6H_2O$) Lithium ion is adsorbed onto aluminum hydroxide, Results obtained show that high Li^+ adsorption was carried out at pH ~ 7 for Urmia lake Also, Lithium ions uptake decreased with increasing temperature from 30ºC to 40ºC. The maximum adsorption amount of 3 $Al(OH)_3$ is at 30 °C, pH = 7 and density 1.31. The obtained results from adsorption Li^+ of Urmia Lake was compared with two isotherm models, Langmuir and freundlich isotherm.[25]

Recent articles have focused on the "different lithium prospects in the Torud district (NE Iran) using the staged factor analysis (SFA) and power spectrum-area (S-A) modeling based on stream sediments and lithogeochemical data…There are three classes for geochemical anomalies…These anomalies were correlated with lithogeochemical data utilizing logratio matrix which show that the main prospect based on the SFA and S-A fractal model is located in the NE part of the Torud region within magmatic rocks".[26]

A 2021 Farsi journal article looked at the determination of lithium resources in seawater in the Southern Coast of the Caspian Sea and River Estuaries. "The sea is a rich source of lithium; its analysis in the Caspian Sea has been evaluated using flame atomic emission spectrometry…Results showed that the concentration of lithium is reduced with increasing distance from the coastline".[27]

A recent study looked at the feasibility of using the capabilities of Sentinel-2 image and the FieldSpec3 spectro-radiometer in mapping five important lithium-containing minerals. The minerals included spodumene, lepidoloite, amblygonite, petalite and eucryptite.[28]

"Therefore, first the FieldSpec3 spectro-radiometer was used to create the spectral curves of the LCMs. Then, accurate spectral analysis and comparison of the studied LCMs were performed using The Spectral Geologist (TSG) and the Prism software. These two software can show even slight difference in absorption features of different LCMs, which can discriminate and identify these minerals. Lithium-bearing rocks show absorption features at ∼365, ∼2200, and ∼2350 nm and reflective features at ∼550–770 nm. These features are consistent with Sentinel-2 bands. Therefore, the created spectral curves were utilized for calibration of Sentinel-2 optical image to detect and map the potential zones of the rock units containing minerals mentioned above in a part of the central Iranian terrane. By using the Spectral Angle Mapper (SAM) classifier module, the potential areas were demarcated. Out of the five LCMs, petalite and spodumene showed more extensive coverage in the study area. Generally speaking, the largest concentration of those LCMs can be seen in southern and central eastern parts of the study area."[29]

Satellite imagery has also been used to analyze drying trends affecting Lake Urmia. More than "70% of the lake died and more than two-thirds of its water converted into the salt marsh and salt density of it also has more than 400 grams per liter".[30]

An undated PowerPoint Presentation found a Chinese government website gives a brief review on the aspect of mining activity in Iran. A variety of mineral and ore deposits throughout Iran are examined in this review which also looks at opportunities for mutual cooperation.[31]

A 2010 conference presentation in Farsi by researchers from Payame Noor University looked at the extraction and measurement of very small amounts of lithium in highly concentrated solutions of minerals and natural salts.[32] A year later a journal article by these same researchers came out which stated “we have developed a method for removing of mineral salts in brines based on the interactions of cations, crown ether and heteropoly acid in order to determine trace amounts of lithium by flame emission spectrometry”. The procedure was applied to trace lithium determination in natural brines of Khoor Playa located in the central Kavir of Iran.[33]

An improved procedure for determining traces amount of lithium in natural brines by a flame photometric method was reported in a 2018 Farsi journal. A Schiff base ligand in ethanol showed good complex formation with Li+ ion. The lithium was then extracted by a ligand modified C18 disk and determined by use of a flame photometer.[34]

Barzegari developed a process for extraction of lithium brines.[35] He later helped develop a process for selective extraction of lithium from low-grade Gypsiferous clays. “In this study, an effective method way provided to extract the maximum amount of lithium from clay deposits while minimizing extraction of magnesium and calcium ion. After pre-feasibility studies on extraction methods, the limestone-gypsum roasting with water-technique was selected for further studies…The highest lithium recovery of 75.65% was obtained at a furnace temperature of 1100C. In both cases, magnesium was completely removed and the maximum content of calcium in the leach solution was 0.1%”.[36]

The recovery of lithium as lithium aluminate from Urmia Lake was reported on in a 2016 conference presentation. A co-precipitation method which utilized aluminum chloride hexahydrate and lithium ions were selectively absorbed onto aluminum hydroxide. “Results obtained show that high Li+ absorption was carried out at pH ~7 for Urmia Lake”.[37]

Ian Steward and Nick Gillard, Project Alpha Centre for Science and Security Studies, King’s College London, published a very important report entitled “The AEOI Files – Proliferation Case Study Series” analyzed a 136 page research prospectus that was produced in 2006 by the Atomic Energy Organization of Iran. As part of this effort Project Alpha looked at MSc and PhD students from Sharif University in a number of nuclear science related areas. One area that was neglected in their analysis pertains to lithium related research.[38]

Searching the Sharif University library (sdr.library.sharif.ir) yielded a number of important lithium related thesis. Seven of these thesis concerned the extraction and purification of lithium ions from Urmia Lake brines.[39]

The Sharif University MSc. thesis advisors included Masoud Askari, Mohammad Nusheh, and Ali Asghar Alamolhoda. Detailed background and current information regarding these professors is provided in Appendix C.

Searching the open source literature revealed that Askari was the Chairman of the Materials Innovation and Process Engineering (MIPEC), Research Vice-Chancellor of the Faculty of Engineering and Materials Science (Sharif University), Head of the Metallurgy Department (Sharif University), Head of the Scientific Council, Institute of Higher Education (Jihad

University), Ex-Chancellor of Sharif University – International Campus, Kish Island, and Scientific Advisor of the Iran Scientific and Industrial Research Organization.[40]

Mohammad Nusheh graduated from Sharif University with a PhD in 2010 and served as an Invited Lecturer at the Materials Science and Engineering Department, Sharif University. He also was an Assistant Professor at Islamic Azad University, Zanjan Campus. Since 2017 he has been the Lead R&D Scientist and co-founder of Hot Lime Labs located at Lower Hutt, New Zealand.[41]

Ali Asghar Alamolhoda is the Director, Institute of Water and Energy, Sharif University, Secretariat of Desalination Committee, Ministry of Science and Technology, Secretary of the Water Affairs Committee of the Iranian Vice President's Office and may possibly related to the Cleric Ahamd Alamolhoda.[42] The current President of Iran Ebrahim Raisi's wife Jamileh Alamolhoda is a member of the Cleric family.[43]

In November of 2017 Alamolhoda, director of the Institute of Water and Energy Research at Sharif University visited ISL (Qinghai Institute of Salt Lakes) and was hosted by Wu Zhijian (deputy director of ISL). Ma Xiaomin of the Chinese Academy of Sciences Literature and Information Center spoke about the construction of a new joint research for water and environment in Iraq.[44]

Alamolhoda gave the Welcome Speech at the Workshop on Salts and Chemical Extraction from Saline Water for IORA Countries that was held on October 15-17, 2019. The workshop was hled in cooperation with the Institute of Seawater Desalination and Multipurpose Utilization (ISDMU), Tiannjin, China.[45]

Selective adsorption of Li+ ion from seawater was evaluated using inorganic nanostructured absorbents such as aluminum, manganese, titanium and zirconium oxide nanotubes. "Simultaneous improvements of adsorbent stability and adsorption capacity were investigated by insertion of cobalt into the spinel structure of lithium manganese oxide and optimization of the adsorbent preparation conditions…Experiments were designed by using Design Expert Software". [46]

"The characterization and application of a new ion exchange composite, manufactured by poly vinylidene fluoride (PVDF) for recovery of lithium from natural brine. Synthesized MnO_2 nano-particles (HMO, final MnO_2 ion-sieve) having high selectivity for lithium adsorption were used as inorganic ion-exchange adsorbent. Subsequently, the lithium ion exchange composite (CHMO, final MnO_2 ion exchange composite) was prepared by dissolving PVDF in *N*-methyl-2-pyrrolidone, and mixing with (HMO) in equal ratios. The produced polymeric solution acts as a binder and support to closely bond HMO together into a homogeneous three-dimensionally interpenetrating network after drying at 220°C. This composite presents a mesoporous/macroporous structure which allows free channel of the solution. It exhibits considerable Li^+ adsorption capacities of 19.22 and 11.06 mg(Li^+) g^{-1} (CHMO) in LiOH solution and lithium-enriched Lake Urmia, respectively. Efforts for improvement of the overall performances of CHMO are still in progress".[47]

The use of various crown-ethers such as benzo-15-crown-5 and 12-crown-4 as extracting agents from artificial seawater was also evaluated. “In this work, transport of lithium (Li) ions from seawater into an aqueous phase was performed by using a liquid membrane (LM) and 12-crown-4 as a carrier. Influential parameters on the extraction efficiency of Li including the pH of the feed and receiving phases, type of membrane solvent, carrier concentration, type & concentration of the stripping reagent in the receiving phase and its pH, temperature and time of transport were investigated and optimized. The effect of carbon nanotubes (CNTs) as an additive on the transportation of Li ions was evaluated. The results show that single walled carbon nanotubes (SWCNTs) have a positive effect on the Li transportation. Under the optimized conditions, the maximum Li transportation from the feed into the receiving phase was 12.0%. The selectivity of the proposed method in the presence of interfering ions such as Na^+, K^+, Ca^{2+} and Mg^{2+} was more satisfactory than that of reported methods. The method was successfully applied for the separation of Li from seawater samples”.[48]

Australian, Chinese and Iranian researchers recently wrote an extensive review that looks at “different liquid lithium extraction methods, lithium ion-sieve (LIS) technology is an emerging recovery method with great advantages over other approaches. LIS adsorption is a promising method for Li extraction owing to its low energy consumption, high lithium uptake capacity, environmentally friendly nature and superior lithium selectivity properties. A variety of physical and chemical methods can be applied to extract lithium from brines and ores. The present work critically reviews recent developments in lithium extraction and recovery using LIS adsorbents and membranes from aqueous solutions such as brine, seawater, etc”.[49]

Nader Stoudeh while on sabbatical from Yasouj University was part of a research project on Lithium Ore Processing, School of Engineering, Edith Cowan University, Australia. This project looked lithium recovery from lepidolite, petalite, and spodumene ores using a sodium sulfate ore roasting process. Solution analyses indicated that 99% lithium dissolution could be achieved for mixtures with 1:1 mass ratio after heating at 1000C for 1 hr.[50]

Section III:

In a now dated resume Abouzar Kiyani states that he had worked on research for the separation of boron isotopes using laser isotope separation and the separation of lithium isotopes by physical and chemical means. No further open source information was found concerning this lithium isotope separation research. His resume indicates that he received his BSc. Degree in nuclear physics from Malek Ashtar University in 1989, and his MSc. in nuclear from Imam Hossein University in 1993.[51]

A 2011 journal article lists his affiliation with the Department of Physics, Islamic Azad University.[52] A 2013 journal article lists him as a PhD student at Payam Noor University however researchgate lists him as a PhD student with the Department of Physics, Arak University.[53]

Three MSc thesis (Aryanpur, Kowsari and Azad) on Lithium isotope separation using the amalgam electrolysis method were located on the Sharif University website with Mohammad

Outokesh and Javad Ahmadi listed as advisors. The earliest thesis is dated 2010 which probably means research was started in 2008.

A search of the open literature revealed that Ahmadi is associated with the Nuclear Science and Technology Research Institute.[54] Outokesh is an Associate Professor of Energy Engineering at Sharif University.[55]

Both Outokesh and Ahmadi are subject to US sanctions for their association with Iranian nuclear weapons related activities. Reviewing the open source literature reveals four conference presentations on lithium isotope separation during the years 2013-14.[56]

The lead author listed on these conference presentations is listed as Kosari and is believed to be Mohammad Reza Kowsari who is listed on the Sharif repository site as the author of a 2013 MSc thesis on Lithium Isotope Separation by Electrolysis Amalgam by a Continuous Method.[57]

This thesis (2013) is notable for the following "The main use of 6Li, however, is as the source of tritium producing and used in nuclear fusion reactor. In 1388s, first experiment on lithium isotope separation by electrolysis carried on laboratory scale and batch method in IRAN. In this project imply same separation method but distinction is the scale is pilot and continuous method is chosen and important parameters have been studied. In this method, is used from mercury cathode and lithium hydroxide as feed which flow counter current into electrolysis cell. Implied anodes materials are stainless steel and coated titanium with ruthenium oxide. Parameters in this experiment are feed and mercury flow rate, lithium hydroxide concentration, current, anode type and amount of implied anode surface. Effect of each parameter studies on separation factor, efficiency, amount of lithium lost in feed and amount of lithium gained in product. In this project, separation is done by separation factors in range of 1.02 to 1.122 in single stage and in each step enrichment level was 0.2% and even was reached to 0.5%".[58]

A reference was found to an undated MSc thesis by Mohammad Kosari on the use of a Caster-Keller cell for lithium isotope separation by a continuous method.[59] The Caster-Keller cell was originally developed for the commercial preparation of sodium hydroxide by the electrolysis of sodium chloride solutions.[60]

An earlier thesis (2010) written by Vahid Aryanpur states that "6Li is not only used as a shielding material against thermal neutrons, but also is known as a source of tritium in the blanket of fusion reactors which in turn increase the importance of lithium isotopes separation. Electrolysis is one of the most known lithium isotopes separation methods, involving mercury cathode and a neutral anode like titanium or graphite. In this project mass transfer has been determined as the slowest step which controls the rate of amalgam formation reaction theoretically and practically and the effects of an extensive range of parameters, including types of lithium compounds, temperature of the solution, type of the anode and of course electrolysis of mixture salts as a new idea to reach higher current efficiency and higher separation factor. An acceptable separation has attained for 7Li in twenty stages up to 5% and more than 1% for 6Li in 5 stages, demonstrating a substantial separation factor between 1.04 to 1.06 for LiOH and LiCl respectively.[61]

The third thesis (2015) written by Mohsen Azad states that “Lithium isotope separation in different ways so far been brought into operation. The other aspect to this work, it can be both continuous and batch for action. Lithium isotopes for the first time by electrolysis using the amalgam and mercury as cathode and titanium as an anode and a lithium salt dissolved done. Modelling of separation factor of lithium isotopes in a batch electrolysis cell with mercury cathode was subject of the current study. Modelling of this system can help design of the employed system to use in the separation units. The study investigated effects of different operational parameters including current density, and LiOH concentration and then modelling of them to predict the both momentary and overall separation factors. Between the both examined parameters, effect of current density was found to be the more significant than the other. The maximum single stage separation factor achieved in the present work was 1.136, which was obtained by using the current density of “0.184 Amp/cm2”. Theoretical elucidation of the observed phenomena was accomplished using migration-diffusion theory, and the Bell-Gurneys’ mechanism with special attention onto role of the chemical exchange. Accepting this postulate that “when a rate determining step prevails over the kinetics, its corresponding separation factor will determine separation factor of the system” would greatly simplify the theoretical interpretation”.[62]

Mohammad Reza Kowsari was vital to this program and actually helped supervised Mojsen Azad’s thesis research. Kowsari is listed as an Associate Professor for the Department of Energy Engineering, Sharif University.[63]

The Li6 chemical isotope exchange research effort at Sharif University probably started in early 2008 and continued until at least 2015. Private emails exchanged with a former IAEA inspector indicate that the IAEA knew of Iran’s research in the Li6 isotope exchange area and had inspected the facility that was located at Sharif University at that time.[64]Based on a ceremony held at the Fordow site on August 13, 2019 it is believed that the pilot plant has now been relocated there.[65]

A series of lab scale experiments using different crown ethers was conducted by Mojtaba Shamsipur (Department of Chemistry, Razi University). The stability of lithium complexes with 12-crown-4, 15-crown-5 , 18-crown-6 , dicycolhexyl-18-crown-6, dibenzo-18-crown-6 and benzo-15-crown-5 were studied in various organic solutions such as acetonitrile, nitrobenzene, nitromethane and acetone.[66]

More recent experiments were undertaken by AEOI researchers using the benzo-15-crown-5 system and actual 6Li isotope enrichment factor were measured using inductively coupled plasma-mass-spectrometry.[67]

Section IV:

As part of a study on enrichment of Li^6 using dispersive liquid-liquid microextraction Davoudi mentions the following as regards Li^6 and Li^7 isotopic determination: However, the high price of ICP-MS analysis rebounded that the isotopic separations conditions were chosen on the basis of the least costs and samples which used low volume of solvents., were collected under the best and worst reported optimal conditions. Finally the mass rations of lithium isotopes were obtained as follows: Samples were dried in a furnace in 121 (+/-5) ^oC), near the boiling point of the extraction solvent (tetrachloroethylene), then they were diluted to 6 ml. by adding bidistilled water. The lithium chloride concentration of the feed solution was 0.78 mg L^{-1}. ^6Li and ^7Li were analyzed by inductively-coupled plasma mass spectrometry.[68]

In a 2015 article the "application of derivative spectroscopy, multivariate curve resolution and multivariate calibration methods is proposed for the quantitative determination 6Li and 7Li abundances by inductively-coupled plasma optical emission spectroscopy"[69] was proposed and evaluated. "MCR-ALS and PLS models showed better results, compared to those obtained from the derivative techniques. These results may be explained by the fact that MCR-ALS are full-spectrum techniques, where the simultaneous inclusion of multiple spectral intensities can greatly improve the precision and applicability of quantitative spectral analysis." [70]

The lithium-6 and naturally abundant lithium standard solutions used in this study were prepared by dissolving appropriate amounts of lithium-$^6Li_2$ carbonate (Li_2CO_3, 95 atom% ^6Li) obtained from Aldrich Chemical Company in 0.1 mol L^{-1} HNO_3.[71]

In 2021 two Iranian nationals were charged with allegedly transshipping US-origin mass spectrometers to Iran via the United Arab Emirates. A German-Iranian national allegedly used his small company to procure mass spectrometers on behalf of two Iranian clients. [72] Depending on the sensitivity of these mass spectrometers they may be suitable for the analysis of lithium isotopic ratios.

Section V:

Iran has synthesized, analyzed and characterized a number of lithium ceramics that are suitable for use as tritium breeders. Both silicates and titanates were prepared by hydrothermal and sol-gel methods. These studies were aimed at controlling phase composition and stabilization.[73]

A 2010 MSc thesis by Basu stated that "Lithium-based ceramic, Li_2TiO_3, is being considered as promising solid breeder materials in the tritium breeding blanket of thermonuclear fusion reactors, because of its reasonable lithium atom density, prominent tritium release rate at low temperatures between 200 and 400^oC, its low activation characteristics, low thermal expansion coefficient, high thermal conductivity. For tritium recovery purpose samples having 85-90% of true density with open porosity (around 5%) is required. Uniform small grain size distribution (having diameter between 2-4μm) is preferable as activation energy for tritium diffusion through grain is higher compared to grain boundary. Solid state method requires higher calcination temperature, producing coarser particle and impurity, which adversely affects in achieving high sintered density (above 85% of theoretical density) and forms large grain size with entrapped closed pore inside the grain".[74]

Iranian research supports those conclusions. Ratios of the reactants were varied and "The effect of Li:Ti molar ratio was studied on crystallisation behaviour of lithium titanates. X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR) revealed that the powders were crystallised at the low temperature of 500 °C and the short annealing time of 1 h. Moreover, it was found that Li:Ti molar ratio and annealing temperature influence the preferable orientation growth of the lithium titanate compounds…. The surface area of the powders was enhanced by increasing Li:Ti molar ratio and reached as high as 77 m^2/g for the ratio of Li:Ti = 75:25 at 500 °C. This is one of the smallest crystallite size and the highest surface areas reported in the literature, and the materials could be used in many applications such as rechargeable lithium batteries and tritium breeding materials”.[75]

The effects of hydrothermal synthesis and sintering were studied to determine the morphology of lithium titanates. “Lithium metatitanate (Li_2TiO_3) is one of the most promising tritium breeding candidate materials. In this study, the nanocrystallites lithium-titanate with hexagonal and cubic crystal structures were synthesized at low temperature, 200°C for 12 h by the hydrothermal method. The results showed that the monoclinic phase of Li_2TiO_3 nanostructure with high purity can be synthesized by further heat treatment of the hydrothermal synthesis powder above 700°C”.[76]

In a subsequent journal article Abbasian states “The use of the hydrothermal method for preparing ceramic composite materials is new trend. In this work, hybrid nanocomposite microspheres of the nanocrystallites Li_2TiO_3 were prepared at low temperature 400°C. Nanocomposite powders synthesized by the batch supercritical hydrothermal method for 12 hours under pressure 12MPa. The raw materials were used containing tetrabutyl titanate ($Ti(C_4H_9O)_4$) as a titanium source, lithium nitrate ($LiNO_3$) as a lithium source, citric acid as a chelating agent and nitric acid as pH controller… XRD result illustrates the microspheres are nanostructure with cubic and monoclinic crystal structures. According to XRD results and using known Scherrer’s equation, the crystallite size of monoclinic phase about 18 nm and monoclinic about 14 nm were determined. The TEM results show that two type of particles morphologies are present in the synthesized microspheres. The first is a spherical shape with a particle size smaller than 100 nm and second is an irregular shape with a particle size between 100 to 200 nm”.[77]

The sintering behavior of lithium metatitanate was measured under a constant heating rate and surface diffusion was determined to be the dominant mechanism of densification on initial sintering of Li_2TiO_3 nanocrystallines.[78]

Two Farsi language journal articles looked at the phase stability of various lithium silicates prepared from lithium nitrate and silicic acid in Li:Si ratios of 1:2 and 1:3. “The hydrothermal method due to advantages of low reaction temperatures and achieving fine particles in synthesized samples was used. Li2SiO3 has orthorhombic structure with Cmc21 space group and cell parameters a=9.392, b=5.397 and c=4.660A. The structure, size and morphology of nano particles were investigated by XRD, FT-IR and SEM analysis methods. In addition, the cell parameters of lithium metasilicate nano particles were determined by CELREF software version3”.[79]

Section VI:

The Tehran Research Reactor is being for irradiation studies and the production of various isotopes used in industry and medical applications. A recent feasibility study looked at the core loading pattern for the production of the isotopes ^{99}Mo, ^{131}I and ^{133}Xe. “In this paper, we have considered three different core loading patterns of Tehran Research Reactor for the economic and optimum production of 99Mo, 131I and 133Xe from low-enriched uranium. These patterns are the large core, the small core with beryllium reflector (SC-Be), and the small core with graphite reflector. Simulation has been performed byMCNPX2.6 to compute the safety calculations, neutron flux changes, and evaluation of mentioned radionuclides production".[80]

An earlier feasibility study looked at the power upgrading of the Tehran Research Reactor for increased radioisotope production. The study stated that "The upgrading study is aimed at investigating the possibility of raising power of the TRR from the current level of 5 MWth to a higher level without violating the original thermal-hydraulic safety criteria. The existing core, comprising 22 standard fuel elements and five control fuel elements, is used for the analyses. Different reactor thermal powers (5–11 MW) and different core coolant flow rates (500–921 m3/h) are considered. It is shown that, for the present core, this goal could be achieved safely by gradually opening the butterfly control valve until the desired coolant flow rate is reached. The TRR power could be upgraded up to around 7.5 MWth with the total power peaking factor maintained at less than or equal to 3.0".[81]

As IAEA coordinated research project looked at the feasibility of "increasing the magnitude of the fast neutron flux inside the flux trap where radionuclides are produced. For this purpose, three new designs of the flux trap are proposed and the obtained fast and thermal neutron fluxes compared with each other. The first and second proposed designs were a sealed cube contained air and D_2O, respectively. The results of calculated production yield all indicated the superiority of the latter by a factor of 55% in comparison to the first proposed design. The third proposed design was based on changing the surrounding of the sealed cube by locating two fuel plates near that. In this case, the production yield increased up to 70%".[82]

A new irradiation instrument for increased isotope production in the Tehran Research Reactor has been designed. "The object of this work is to design an Irradiation Instrument (II) for samples irradiation in Tehran Research Reactor (TRR) which leads to considerable increase in irradiation samples capability of this reactor. After simulation of former and proposed IIs as closely as possible using MCNPX 2.6.0 code in cold condition, the former design results are validated by experimental data. Neutronic parameters optimization is done for new II to have the best neutronic and safe design. This design gives rise to an increase in the irradiation capacity about 48% more than the former plan and a slight improvement in quantity and distribution of neutron flux…Due to constraints such as limited reactor power and relatively small core size, there is restriction on having irradiation places with high neutron flux. Further, due to a relatively much needed time for irradiation of some long half-life isotopes such as molybdenum, there is not enough space with high neutron flux in the core. Then, due consideration for improving this reactor capability is necessary. The design of one instrument with the possibility of numerous samples irradiation as well as regarding the safety and operational problems is a strategy leads to significant improvement in this reactor".[83]

"Different radioisotopes such as Molybdenum, iridium and samarium oxide are produced in the TRR for local medical demands or research purposes. The procedures were developed and applied for radioisotope production at TRR relying heavily on manual handling of the irradiation targets by the reactor operational staff. The advantages thereby are flexibility in the choice of irradiation positions as well as easy access to the reactor core for experiments and operational changes. Although the mentioned advantages, the noticeable exposure of utilizing personnel including operational and health physics personnel and also pollution of containment atmosphere in dispose of irradiated samples are some of these procedure drawbacks….A new II was designed regarding to neutronic, safety and operational circumstances of the TRR for increasing irradiation capabilities, improve operational conditions and enhance safety as the main consequences. After as accurately as possible simulation using MCNPX and verification of results with experimental measurements using RAMS-88 dose calibrator, this new II design demonstrated to be better in performance and safety than the old II layout. The insertion or removal of new II into the core must be conducted according to the new appropriate procedures and operating limits and conditions. This is due to its considerable reactivity worth especially when all irradiation positions are occupied. As a consequence of the TRR irradiation activities improvement, the new proposed II envisages key objectives such as those given in the following;

1. Increasing the capacity of samples irradiation,
2. The possibility of insertion or removal of some samples without reactor shutdown,
3. The possibility of transferring the irradiation box with fuel tool,
4. Elimination of different irradiation samples and related instruments that caused to a more arranged and safe core,
5. A much more safe loading and unloading samples into the core, therefore, decreasing personnel exposure,
6. Knowing the exact position and appropriate neutron flux of each irradiated sample,
7. A more uniform and slightly higher neutron flux.

However, increasing the TRR irradiation capacity approximately 47% in comparison to the old II consequently reduces needed IR positions.

This gives flexibility and rather options to the operating agency for improving this reactor functions in all aspects such as higher quality researches and better fuel management program, aside those mentioned. These results along with the experimental measurements done in the selected IRs make sure that the new II is an acceptable design resulted to more safe, efficient and easier operation including less radioactive hazards to the personnel and others. Also, it is worth mentioning that this proposed design idea could be used in all types of research reactors after considering their appropriate characteristics".[84]

Another journal article published in 2019 looked at a computational investigation of the replacement of the TRR graphite reflector and its impact on thermal neutron enhancement. "Thermal neutron flux enhancement is an essential objective to achieve more radioisotope production in the research reactors. Here, the effect of graphite reflector replacement with other customary reflectors on thermal neutron flux enhancement of Tehran Research Reactor (TRR) core has been investigated. The core is modelled using Monte Carlo-based code with the graphite routine reflector and with Be, BeO, and D_2O reflectors. The calculations showed that the reflector replacement could result in a little enhancement of thermal neutron flux while beryllium oxide is suggested as the most efficient material (about 2.78% on average per channel). In addition, instead of total reflector conversion, application of some dimensionally optimised BeO blocks located around the irradiation boxes increases the thermal neutron flux up to 2.62%. Moreover, this study demonstrates that compacting the core could significantly enhance the thermal neutron flux up to 58% that is noticeably more than the reflector conversion effect".[85]

Another more recent study looked to enhance the thermal neutron flux in the Tehran Research Reactor. "In this study, compacting TRR core configuration, as a method to increase thermal neutron flux in the central in-core irradiation position to provide desired neutronic environment for fuel irradiation tests, is of concern. Several design criteria and limitations, including preservation of enough and suitable irradiation positions in the core for routine radioisotopes production activities of the reactor, have been considered to develop a new compact core configuration for TRR in which, desired linear heat generation rate is achieved in the test fuels and all the neutronic and thermal-hydraulic safety parameters of the proposed configuration are in accordance with the acceptance criteria stated in the reactor FSAR".[86]

Table 2 Produced radioisotopes in TRR core. Produced radioisotope Reaction Approximate production quantity per month Approximate required thermal neutron flux (n/cm2.s) 32P 32S (n,p)32P 500 mCi 6 × 1013 – 7 × 1013 60Co 59Co (n,γ)60Co 1 mCi 7 × 1013 – 8 × 1013 153Sm 152Sm (n,γ)153Sm 3Ci 6 × 1013 – 7 × 1013 131I 130Te (n,γ)131I 9Ci 7 × 1013 – 8 × 1013 166Ho 165Ho (n,γ)166Ho mCi 2 × 1013 – 7 × 1013 188Re 187Re (n,γ)188Re mCi 2 × 1013 – 7 × 1013 177Lu 176Lu (n,γ)177Lu mCi 2 × 1013 – 7 × 1013 99Mo Fission planned 8 × 1013 – 10 × 1013 Various samples neutron activation mg 1 × 1013

"Tehran research reactor (TRR), a fission research reactor, modeled using the MCNP code which the lithium orthosilicate targets positioned in the irradiation boxes. The number of neutrons calculated in the empty irradiation boxes to find the irradiation box with highest neutron flux. Moreover, the number of neutrons calculated in the irradiation boxes which containing quartz tubes. Finally, the mass and density of the hydrogen-3 can be calculated analytically in the irradiation boxes… Since the MCNP code computes the number of generating neutrons per collided particle in the computational cells. So, the number of generating neutrons (neutron flux) in a 5 MW research reactor should be calculated where the fission energy is 200 MeV and the number of releasing neutrons per fission is about 2.4…. Since the TRR is thermal fission reactor and fast neutron energy cross section of 7Li is very low, thus in this study the reaction of 6Li should be important to be calculated. Lithium orthosilicate which encapsulated in quartz tubes, a 1.2 cm lithium orthosilicate height (about 0.15 g) positioned in 12 cm height and 1.8 cm diameter quartz tube, are positioned in each irradiation box. In practice, after irradiation, the quartz capsules mechanically broken in a glove box and the breeder materials remove and place in a tube made of quartz for the out-of-pile experiments… by consumption of 0.15 g lithium orthosilicate about 2 _ 10_10 g of tritium can be produced. This value is comparable to the weight of the tritium produced in the 5 MW Kyoto University research reactor. However, in the Kyoto University research reactor, about 0.3 g encapsulated lithium orthosilicate was irradiated about several minutes…. **According to the power of TRR core, it seems that this method can be used as a source of tritium for fusion engineering research and it is not applicable as an external tritium source for ITER project, which need a huge value of lithium orthosilicate per year to be irradiated".**[87]

An earlier irradiation campaign was said to have occurred in the early 2000s but this information could not be verified.

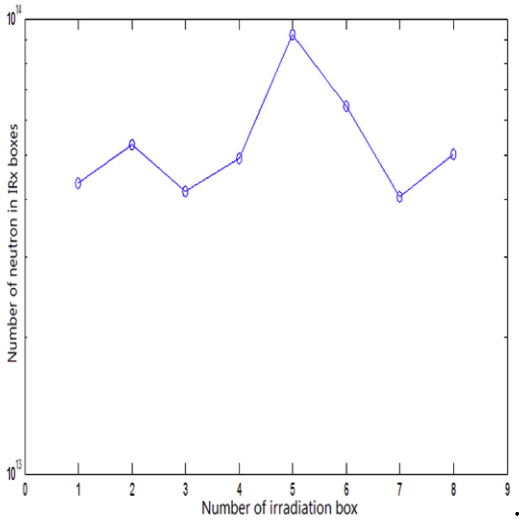

Figure reproduced from journal article [88]

Gheorghe Varasu, who is an international renowned expert in the area of isotope separation, is known to have visited Iran in 2004 for two different nuclear conferences gave at least one presentation on Sources of Tritium. Open sources do not reveal the extent of Varasu's visit although one of the conferences he attended was held in January of 2004 and the other was held in April of the same year.[88]

Section VII:

Proliferation concerns regarding this research will be covered in Volume II of this report.

The safety of the use of tritium as a fuel in a fusion reactor was reviewed in two journal articles. Of interest is the fact that the abstracts of the two articles read the same. One article published in 2004 was in Farsi and the other published in 2006 was in English.[89]

The abstract for the two read articles states "Nowadays, nuclear fusion reaction taken place in systems as fusion Reactors, are the base of a lot of widespread researches to achievement a new source of energy. Although using these kinds of reactors is very beneficial, the optimum usage of them requires sever attention to their effects on human being and his environment. It is shown that the best fuel for fusion reactors is tritium. Tritium is a radioactive isotope of hydrogen with 12.32- year half-life that emits beta radiation. Although its specific activity is relatively weak because of its gaseous state, it can leak easily its ecological effects should be considered. In all around the world, in order to improving safety and reliability of these reactors, researcher groups expandedly investigate radiation hazards resulting from release of tritium and activation products during normal operations as well as accidental conditions. Some of the most significant results and safety aspects are briefly presented in this paper".[90]

Details of “undesirable bio effects” at the Plasma Physics and Nuclear Fusion Research School of the Nuclear Science and Technology Institute (AEOI) two small size Tokamak devices (ALVAND and DAMAVAND) and one medium size Plasma Focus Facility (DENA) were summarized in a 2010 journal article. “Unfortunately during November and December 2005 neglecting the protection principles resulted in some undesirable bio effects in two expert technicians working in DAMAVAND laboratory. They made about 5000 shots in two subsequent months without sufficient protection. The first complications of the radiation absorption such as vertigo and nausea appeared in the first month. After one month i.e. about the first 3000 shots, some more obvious complications appeared in the form of skin eruptions. Other manifestations included alopecia and thyroid function disorders. At the end of second month the film badges showed the absorbed dose resulting from about 5000 shots to be more than 27 mSv….In the 1980s in a 6 year period, 5 married men have been working in ALVAND laboratory and 2 of their children have been born with congenital anomalies. Meanwhile, one of the personnel died because of stomach cancer and one case of sexual dysfunction were reported… Averaging the experimental results in DAMAVAND shows that in areas near the forbidden zone around this device the level of the received dose is very high (more than 6 mSv for each 100 shots). Fortunately, laboratory personnel mostly do not attend this region. With increasing the distance from device the radiation absorption dose decreases and in regions around the control panel and shielding room that personnel usually attend the level of the effective absorbed dose is about 1.16 mSv for each 100 shots”.[91]

A 2012 conference presentation given at the European Medical Physics and Engineering Conference held in Sofia evaluated dose rates for a body phantom behind an ITER bioshield. The same calculations and almost identical assessments were given in a 2014 journal article.

“Dose rates assessment and photon radiation due to the neutron activation of the solid structures in ITER is important from the radiological point of view. Therefore, the dosimetry considered in this case is based on the Deuterium-Tritium (DT) plasma burning with neutrons production rate at 14.1 MeV. The aim of this study is assessment the amount of radiation behind bio-shield wall that a human received during normal operation of ITER by considering neutron activation and delay gammas. To achieve the aim, the ITER system and its components were simulated by Monte Carlo method. Also to increase the accuracy and precision of the absorbed dose assessment a body phantom were considered in the simulation. The results of this research showed that total dose rates level near the outside of bio-shield wall of the tokamak hall is less than ten percent of the annual occupational dose limits during normal operation of ITER and It is possible to learn how long human beings can remain in that environment before the body absorbs dangerous levels of radiation”.[92]

A 2008 journal article describes how a fusion reactor can be used to produce plutonium-239. “It is assumed that there is a fusion reactor has a cylindrical geometry and uses uniformly distributed deuterium–tritium as fuel so that neutron wall load is taken at 10 MWm2 . Moreover, the reactor core is surrounded by six suggested blankets to make best performance of the physical conditions described herein. We determined neutron flux in each considered blanket as well as tritium self-sufficiency using two groups neutron energy and then computation is followed by the MCNP-4C code. Finally, material depletion according to a set of dynamical coupled differential equations is solved to estimate 239Pu production rate. Produced ^{239}Pu is compared with two typical fission reactors to find performance of plutonium breeding ratio in the case of the fusion reactor. We found that 0.92% of initial U is converted into fissile Pu by our suggested fusion reactor with thermal power of 3000 MW. For comparison, ^{239}Pu yield of suggested large scale PWR is about 0.65% and for LMFBR is close to 1.7%. The results show that the fusion reactor has an acceptable efficiency for Pu production compared with a large scale PWR fission reactor type….The tritium for self-sufficient operation in a D–T fusion reactor may be bred by neutron capture in lithium. Also, lithium may be used as a primary coolant. Hence for D–T fusion, one essential use of fusion neutrons is to breed tritium in order to balance the core tritium concentration. Also, immediately adjacent to the fusion core, a region with high isotopic concentration possessing a significant neutron multiplication reactions should be supposed. Moreover, a blanket of fertile material UO2, such that fusion neutrons can breed fissile fuel, is supposed as our goal where fertile blanket can serve fusion reactor as a‘‘fuel factory’’. In addition, a region immediately after the core is considered to be vacuum and then followed by mixtures of high pressure He and tungsten gaseous (80%He + 20%W) to shield a charged particle produced by the fusion. This blanket is essential to protect other facilities from corrosion, bulk, and swelling effects”[93]

A 2013 looked at the amount of tritium produced in the blanket of a fusion reactor without mentioning the lithium ceramic being considered for use. “For the preparation of tritium fuel as the main and rare fuel of reactors in the fusion reactors, the reactor blanket must be designed so that it provides enough tritium breeding ratio. The tritium breeding ratio, TBR, in the blanket of reactors should be greater than one, (TBR > 1), by applying lithium blanket. The calculations for proposed parameters (η and ,,*dbtfpt*), indicate that the estimated tritium breeding ratio is greater than one. The calculated TBR = 1.04 satisfies the tritium provision condition….In this scheme, the ratio of tritium breeding in reactors with lithium blanket is estimated by considering of the possible reactions in the plasma and reactor blanket, Tritium breeding ratio based on the recycle time and dou- bling time are plotted in Figures 3 and 4. Figure 3 shows that TBR increases by the increasing of recycle time with different of burn up fraction consumption parameters (and η = 0.5). Also, it can be seen that with increasing the doubling time, tritium breeding ratio is always greater than one (Figure 4). For example, with parameters, η = 0.5 and with a doubling time, the tritium breeding ratio is approximately 1.04. This amount will secure the condition of fule supply, then for a reactor design with TBR > 1, it is necessary that the doubling time, the tritium burn fraction and the injection efficiency must be longer and the recycling time must be smallest”.[94]

Researchers from the Department of Energy Engineering and Physics, Amirkabir University calculated using the MCNP-4C Monte Carlo code the tritium breeding ratio for a Helium Cooled Pebble Bed Blanket with Li4SiO4 as the ceramic breeder. 6Li ratios were varied and tritium cross sections were calculated. “Also for self-sustainability of ITER, 20 % enriched 6Li was required versus that is 90 % in Li4SiO4 ceramic breeders. Thus, production cost of the developed HCPB would be lower than the primary”.[95]

“In this paper, neutronic calculations were performed to obtain tritium breeding ratio (TBR) for ITER device using developed helium cooled pebble (HCPB) blanket. The designed blanket module has the following combinations; natural lithium, Li_4SiO_4 (20 %), beryllium moderator and neutron multiplier. To ensure tritium self-sufficiency, the calculated achievable TBR should be equal to or greater than the required TBR. Simulations have been performed by means of Monte Carlo MCNP-4C code using END/B-VII.1 data library. Results show that TBR of 1.14 is obtained for this new HCPB….In this paper, HCPB blanket was designed by Li_4SiO_4 ceramic breeder and TBR was calculated for this new blanket using MCNP-4C Monte Carlo code. We used tally F4 to obtained neutron flux by MCNP-4C code. Because of using helium for cooling in this type of blanket and pebble bed structure of Li4SiO4 ceramic breeders, that is known HCPB….Since enriching 6Li was so expensive and also 7Li was abundant in natural lithium (92.6 %), 6Li and 7Li were simultaneously used. Tritium breeder zone with 7Li was located after the first wall and its thickness was 1 cm. Using neutronic calculation, optimization of Be, breeder thickness and lithium enriching were done to achieve suitable TBR….To design a good HCPB blanket configuration, we performed all neutronic calculations by means of MCNP-4C Monte Carlo code using the ENDF/B-VII library….In this paper we calculated the possibility of designing a new HCPB breeding blanket to the ITER device. Neutronic calculations were performed considering the HCPB-TBM module in the equatorial port and the entire ITER was covered by breeding blanket. The first calculations were used in order to assess the model and compared the obtained results with others in the literature. Then, the developed HCPB blanket was designed by the same TBR. In this new design total radial thickness of blanket module increased whereas total breeder thickness decreased".[96]

Further calculations by this group were carried out using the MCNPX Monte Carlo code to achieve more accurate figures regarding the tritium breeding ratio in a D-T fusion power reactor. 6Li isotopic levels in Li4SiO4 were gradually increased up to the 90% in a step by step process.

Nima Ghal-Eh, Hossein Afarideh and Gholam Reza Ettati posted on researchgate.net a copy of pages of MCNP 2.6 Manual version (Appendix I) that are marked For Official Use Only – Export Controlled Information. The pages comes from the MCNPX User's Manual, Version 2.6.0, April 2008, LA-CP-07-1473.[97]

"In this study, the neutronic calculation to obtain tritium breeding ratio (TBR) in a deuterium-tritium (D-T) fusion power reactor using Monte Carlo MCNPX is done. To this end Li_4SiO_4 was considered as the blanket module. In order to improve the distribution of power density in the blanket module, an arrangement of the neutron multiplier Be in the breeding zone has been optimized. Total TBR of 1.14 is achieved. Finally helium cooled pebble bed (HCPB) was designed as cooling system using COMSOL Multiphysics simulator"…. To ensure tritium self-sufficiency, the calculated TBR must be equal or greater than the minimum required TBR. In this paper using Monte Carlo code (MCNPX 2.6) [4,5], the tritium breeding ratio considering self-sufficiency has been calculated…. Eventually total TBR of 1.14 for ITER reactor with HCPB blanket is achieved which is sufficient for reactor tritium self-sufficiency. The required TBR should exceed unity by a margin to compensate the tritium losses and radioactive decay of tritium during the period between production and use in the reactor, supply inventory for start up of other reactors and moreover to provide reserve storage inventory for continued reactor operation during a failure in a tritium processing line".[98]

A 2019 design simulation Sadeghi stated "we simulated an appropriate model for an advanced breeding blanket of future TOKAMAK fusion reactors with solid breeder (Li_4SiO_4) building material in the form of pebble beds, ODS ferritic steel as structural material and Beryllium as neutron multiplier. With the MCNPX code, the efficiency of this proposed model for the production and self-sufficiency of tritium was investigated. Total tritium breeding ratio of 1.15 is achieved. The helium cooled pebble bed system and parameters of temperature and pressure are investigated by COMSOL Multiphysics simulating software. The temperature of Helium as cooling gas never exceeded 530Co all and the tolerable temperature of beryllium was obtained 650Co. In the proposed design, it is adequate to enrich the $_6$Li to 40%....Beryllium pebbles of 1mm diameter are used in pebble beds of the HCPB concept as neutron multipliers to increase the efficiency of tritium generation and to achieve an overall TBR greater than one. The volume of these beds is about 2 to 3 times larger than the Lithium ceramics. These ceramics such as Lithium Orthosilicate (Li4SiO4) in pebbles with a typical diameter of 0.4–0.6 mm are the primary candidates for structural materials in the TBM and in the DEMO breeding blanket designs [13-15]. The design temperature limit of ceramic breeder Lithium Li4SiO4 is 920 °C, which is about 100 °C lower than the melting point….6Li is the more useful one and can easily be enriched for use in a breeding blanket. The TBR which is defined as the average number of tritium atoms bred per tritium atom burnt in the reaction D-T must be more than one, for a self- sustained fusion economy (TBR>1). The feasibility of tritium breeding depends on both basic physics and engineering issues. Neutronics calculations of the proposed blanket module are accomplished by using the Monte Carlo simulation MCNPX code. The amount of produced tritium in the module is calculated by F4 Tally and MT card with interaction number 205. The achievable TBR depends on the thickness of the blanket….For better breeding, as calculated with the MCNPX code, it is proposed that the Li6 enrichment in the ceramic breeder beds should be increased 20% for the front of the module and up to 40% for the back of it”.[99]

In more comprehensive journal article looking at the use of Li_4SiO_4 as the ceramic tritium breeder Sadeghi stated “In this study, the neutronic calculation to obtain tritium breeding ratio (TBR) in a deuterium-tritium (DT) fusion power reactor using Monte Carlo MCNPX is done. In addition, by using COMSOL software, an efficient cooling system is designed. In the proposed design, it is adequate to enrich up to 40% 6Li. Total tritium breeding ratio of 1.12 is achieved. The temperature of helium as coolant gas never exceed 687_C. As regards the tolerable temperature of beryllium (650_C), the design of blanket module is done in the way that beryllium temperature never exceeded 600_C. The main feature of this design indicates the temperature of helium coolant is higher than other proposed models for blanket module, therefore power of electricity generation will increase…Total surface area of the DEMO blanket is 1188 m2 and the plasma facing surface area in our proposed design is 1.2m2. Therefore 990 HCPB test blanket modules (TBM) are needed for the total area of the blanket. Each module has a number of different parts. The TBM is basically composed of breeder units (BU) and cooling channels. The BU contain lithium orthosilicate and beryllium pebble beds….For better breeding, as calculated with the MCNPX code, it is proposed that the 6Li enrichment in the ceramic breeder beds should be increased 20% for the front of the module and up to 40%”.[100]

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4. **Thesis:**

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Implementation of the Unfolding Code FERDOR

R. Koohi-Fayegh, Thesis (PhD), 1980, University of Birmingham, UK
Neutron Spectrum Measurement in a LiF-Be Assembly Using a Miniature NE-213 Spectrometer

Ferdowsi University of Mashhad, Department of Physics website
The profile of Kohhi-Fayegh is out date and provides very little useful information on his background, publications (conference, journal, and reports), teaching duties at the university.

The beryllium spheres used in these experiments were provided by the Atomic Weapons Research Establish (AWRE) and was the beryllium purity was at a minimum 98%.

The author has a detailed collection of Koohi-Fayegh publications and abstracts are included in Appendix A.

5. This quote is taken from the Synopsis section of Koohi-Fayegh’s PhD thesis.

6. The miniature spectrometer system used in this study was developed in the earlier stages of this program by Lindsay John Perkins and is described in detail in his Ph.D. thesis.

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The websites for Masoud Askari do not reference the MSc students he supervised in the lithium area. Mention is made of Mohammad Nusheh who was a PhD student of his but there was no reference to the title of Nusheh's research.

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Nuclear Engineering and Technology, 2020, Vol. 52, pp323-327

Appendix A: Early Iranian Scientific Researchers – Proliferation sensitive research

Selected Publications

Fereydoun Abbasi Davani

Head of the Atomic Energy Organization of Iran (AEOI)

Professor of Physics, Shahid Beheshti University

FA Davani, GR Etaati, H Afarideh, RK Fayegh, GR Aslani, Neutron spectrum measurement in D+ Be reaction, Iranian Journal of Physics Research 2002, 3 (2), 101-107

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S Jamili, E Bayat, H Afarideh, FA Davani, N Ghal-Eh, Digital neutron-gamma discrimination in a wide energy range using pulse reconstruction method, Radiation Physics and Chemistry 2015, Vol. 109, p13-16

ZS Rad, FA Davani, B Shirani, Investigation of deuterated target effects on neutron yield in plasma focus device SBUMTPF1, Journal of Plasma Physics 2015, 81 (2), 905810209

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S. Mohtashami, H. Afarideh, F. Abbasi Davani and R. Ghaderi, A dual-energy pyroelectric accelerator, Journal of Instrumentation, 2021, Vol. 16, P10017

Gholam Reza Etaati

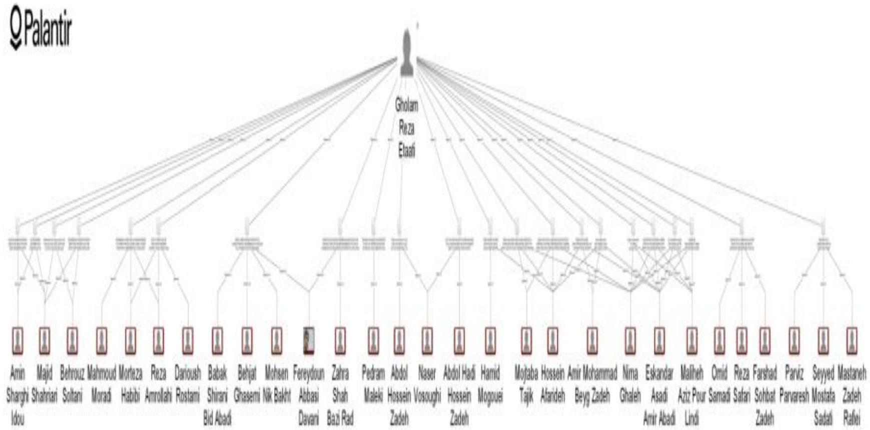
Physics and Energy Engineering Deaprtment, Amirkabir University

C4ADS

innovation for peace

ANALYSIS POWERED BY

Palantir



Assistant Professor, Energy Engineering and Physics Department, Amirkabir University, July 2007 to present

Currently at Energy Engineering and Physics Department, University of Tehran

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Rahim Koohi-Fayegh Publications

Thesis (MSc.), 1977, University of Birmingham, UK
Implementation of the Unfolding Code FERDOR

Neutron Spectrum Measurement in a Beryllium-Lithium Fluoride Assembly using an NE 213 Scintillator, PhD, Department of Physics, University of Birmingham, September 1980

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Physics Department, Ferdowsi University
School of Physics, Damghan University of Basic Sciences
Nuclear Engineering and Physics Department, AmirKabir University
Photocathode non-uniformity contribution to the energy resolution of scintillators, Radiation Protection Dosimetry; 2010, Volume: 140; Journal Issue: 1

Hossein Afarideh

H. Afarideh, Thesis (M.S.), 1985, University of Birmingham, UK
Development of New Techniques for Automatic Track Counting

H. Afarideh, Thesis (PhD), 1988, University of Birmingham, UK
Investigation of Light Particles in Ternary and Binary Fission of ^{251}Cf and ^{238}U

April 2002 – 2005:
Member of the PhD council of the Nuclear Science Department of the Amir-Kabir Industrial University

April 1999- 2005:
• Member of the Editorial Board of the AEOI Scientific Journal

Jan 2002 – to present:
• Prof. of Physics & Nuclear Sceince in AmirKabir Industrial University

Managed 3 PhD thesis
Managed 117 MSc thesis

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Javad Rahighi

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Manijeh Rahbar

No picture available

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Department of Physics, University of Tehran

Nima Ghal-Eh

School of Physics, Damghan University, Damghan, Iran, 2017 to present
Previously associated with Department of Physics and Nuclear Science, Amirkabir University
PhD Physics, 2003, Ferdowsi University of Mashhad

Ghal-Eh N, Scott M, Koohi-Fayegh R, A photon transport model code for use in scintillation detectors, Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, (2004), Vol. 516(1), p116-121

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Ghal-Eh N, Doostizadeh H, Hazami Z, A Compton-suppression detection system for use in manganese bath measurements, Radiation Physics and Chemistry (2015) Vol. 112, p 34-39

Tajik M, Ghal-Eh N, Comparison of light transport-incorporated MCNPX and FLUKA codes in generating organic scintillators responses to neutrons and gamma rays, Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment (2015), Vol. 791,p 65-68

Lotfi Y, Etaati G, Doust-Mohammadi V, Ghal-Eh N, Design and Fabrication of a Data Acquisition System for Pulsed Neutron Flux Measurement of Plasma Focus Devices, Journal of Fusion Energy (2015), Vol. 34(2), p411-421

Jamili S, Bayat E, Afarideh H, Ghal-Eh N, Digital neutron-gamma discrimination in a wide energy range using pulse reconstruction method, Radiation Physics and Chemistry (2015), Vol. 109, p13-16

Bayat E, Afarideh H, Davani F, Ghal-Eh N, A quality survey on different shielding configurations of gamma ray detector used with a portable PGNAA system, Radiation Physics and Chemistry (2016) Vol. 120, p7-11

Ghal-Eh N, Ahmadi P, Doost-Mohammadi V, A quantitative PGNAA study for use in aqueous solution measurements using Am-Be neutron source and BGO scintillation detector, Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment (2016) Vol. 808, p123-127

Appendix B: Institute of Applied Physics – Publications

Neutron Spectrum Measurement of D + Be Reaction
Iranian Journal of Physics Research, 2002, Vol. 2, p101-107, *F. Davani Abbasi, **G.R. Etaati, ***H. Afarideh, ****R. Koohi Fayegh and *****G.R. Aslani
*AmirKabir University of Technology
**Iran University of Science and Technology, Institute of Applied Physics
***Atomic Energy Organization of Iran
****Ferdowsi University
*****Atomic Energy Organization of Iran, Department of Nuclear Research Center for Agriculture and Medicine, Karaj

Statistical Theory for the Kardar-Parisi-Zhang Equation in (1+1) Dimensions
Physical Review E, 2002, Vol. 65, 026132, *A.A. Masoudi, *F. Shahbazi, **J. Davoudi and ***M. Reza Rahimi Tabar
*Department of Physics, Sharif University
**Max-Planck Institute for Complex Systems, Dresden, Germany
***Institute of Applied Physics, Iran University of Science and Technology

Dynamical Phase Transition of a One-Dimensional Kinetic Using Model with Boundaries
Physical Review E, 2002, Vol. 65, 056129, M. Khorrami and *A. Aghamohammadi
*Institute of Applied Physics, Iran University of Science and Technology

Cluster Approximation Solution of a Two-Species Annihilation Model
Physical Review E, 2002, Vol. 65, 066136, F. Tabatabaee and *A. Aghamohammadi
*Institute of Applied Physics, Iran University of Science and Technology

Fabrication of Preamplifier for Proportional Counter
Meeting of Nuclear Physicists and Experts in Iran, February 20-21,2002, Shahreza Islamic Azad University, Iran, *Y. Lofti, **M. Yazdanpanah, ***B. Talebi, ***A. Mohammadi and ***G. Etaati
*Institute of Applied Physics, Iran University of Science and Technology
**Institute of Applied Science, Imam Hussein University
***Imam Hussein University

Exactly Solvable Models through the Empty Interval Method, for More-Than-Two-Site Interactions
Journal of Physics A, 2003, Vol. 36, p345-357, *M. Khorrami, **A. Aghamohammadi and ***M. Alimohammadi
*Institute for Advanced Studies in Basic Sciences, Zanjan, Iran and Institute of Applied Physics, Iran University of Science and Technology
**Department of Physics, Alzahra University and Institute of Applied Physics, Iran University of Science and Technology
***Physics Department, University of Tehran and Institute of Applied Physics, Iran University of Science and Technology

Spin O and Spin ½ Quantum Relativistic Particles in a Constant Gravitational Field
Annals of Physics, 2003, Vol. 304, M. Khorrami and M. Alimohammadi

Discrete Scale Invariance and its Logarithmic Extension
Nuclear Physics B, 2003, Vol. 655, p342-352, N. Abed-Pour, *A. Aghamohammadi, M. Khorrami and M.R. Rahimi Tabar
* Department of Physics, Alzahra University and Institute of Applied Physics, Iran University of Science and Technology

Exactly Solvable Models through the Generalized Empty Interval Methods, for Multi-Species Interactions
European Physics Journal B, 2003, Vol. 31, p371-378, *A. Aghamohammadi, **M. Alimohammadi and M. Khorrami
* Department of Physics, Alzahra University and Institute of Applied Physics, Iran University of Science and Technology
** Physics Department, University of Tehran and Institute of Applied Physics, Iran University of Science and Technology
*** Institute for Advanced Studies in Basic Sciences, Zanjan, Iran and Institute of Applied Physics, Iran University of Science and Technology

Fabrication of Preamplifier for Proportional Counter
Meeting of Nuclear Physicists and Experts in Iran, February 20-21, 2002, Shahreza Islamic Azad University, Iran, *Y. Lofti, **M. Yazdanpanah, ***B. Talebi, ***A. Mohammadi and ***G. Etaati
*Institute of Applied Physics (Iran University of Science and Technology), Tehran
**Institute of Applied Science, Tehran
***Imam Hossein University

Circuitary Analysis of Non-Linear Behavior of Photomultiplier
Meeting of Nuclear Physicists and Experts in Iran, February 20-21, 2002, M. Sepahvand, M. Shahriari and F. Abasi
Work performed by AmirKabir University, Imam Hossein University, Physics Research Center

Growth of Single Crystal LiF:Mg,Ti for Thermoluminescence Dosimtery Meeting of Nuclear Physicists and Experts in Iran, February 20-21, 2002, *Kh. Mohammadi, *P. Katani, *A. Rasouli, *N. Banaei and *M. Noohi
*Applied Physics Institute, Tehran

Production of TLD-100 Chips and Characterization of its Dosimetric Properties
The Effects of Low and Very Low Doses of Ionizing Radiation on Human Health, Shahid Beheshti University, October 21-3, 2003, P. Katani, Kh. Mohammadi and Shahram Amiri
Work performed at the Applied Physics Institute, Tehran

Design Made and Optimization of Rechargable Standard Geiger-Muller Tube
The Effects of Low and Very Low Doses of Ionizing Radiation on Human Health, Shahid Beheshti University, October 21-3, 2003, P. Katani, K. Mohammadi and Shahram Amiri
Work performed at the Applied Physics Institute, Tehran

Mahdi Tehranchi named IAU president

August 20, 2018

Excepts in this section come from the website Iranredline.

TEHRAN – The Islamic Azad University (IAU) Board of Trustees have elected Mohammad Mahdi Tehranchi as the new president of the IAU, Tasnim reported on Sunday.

Since 1998 Tehranchi served as the president of Shahid Beheshti University and Islamic Azad universities in Tehran. He also acted as deputy chief of the Science and Technology Research Center of the Expediency Council.

He was elected during a meeting attended by the majority of the IAU Board of Trustees, replacing Farhad Rahbar who served as the IAU president from July 16, 2017 to August 19, 2018.

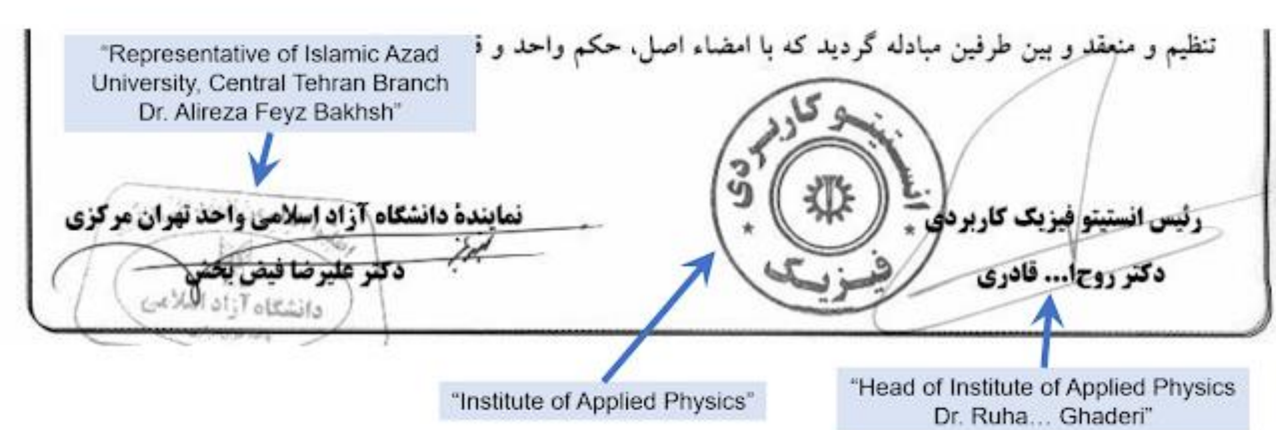
THE IAP IS BACK - AND PUTTING IRAN'S BIGGEST UNIVERSITY AT RISK OF SANCTIONS: PART II

DECEMBER 12, 2019

In our last post, we revealed documents showing that in 2016, SPND used the IAP as a nom-de-plume to sign a memorandum of cooperation with Iran's oldest and most prestigious private university, the Islamic Azad University Central Tehran Branch (*دانشگاه آزاد واحد تهران مرکزی*).

There is a lot of evidence in there that the SPND is behind it. Let’s take a closer look:

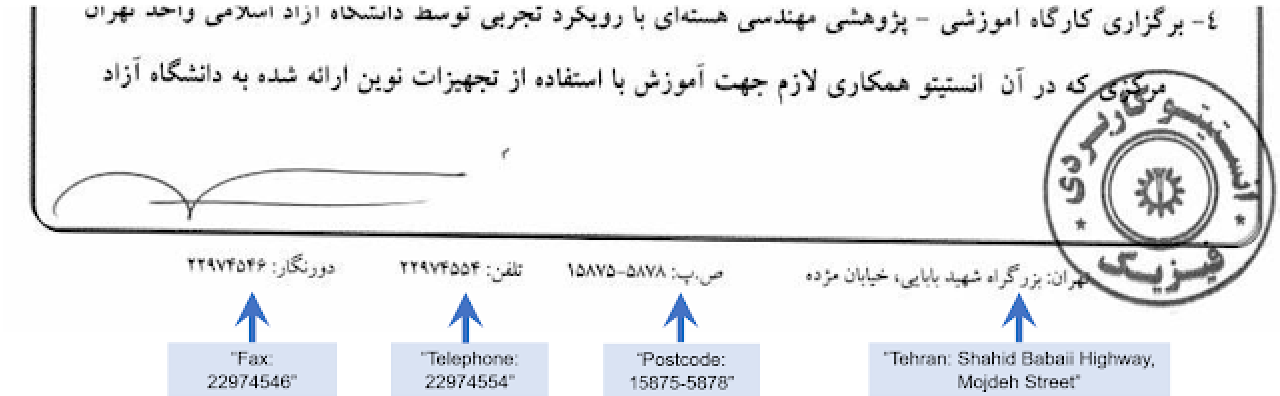
First, the document is signed by Dr Rouhollah Ghaderi (*روح الله قادری*), who is described in the document as the head of the IAP. Here is Ghaderi's signature below on the contract, using a shortened version of his first name:



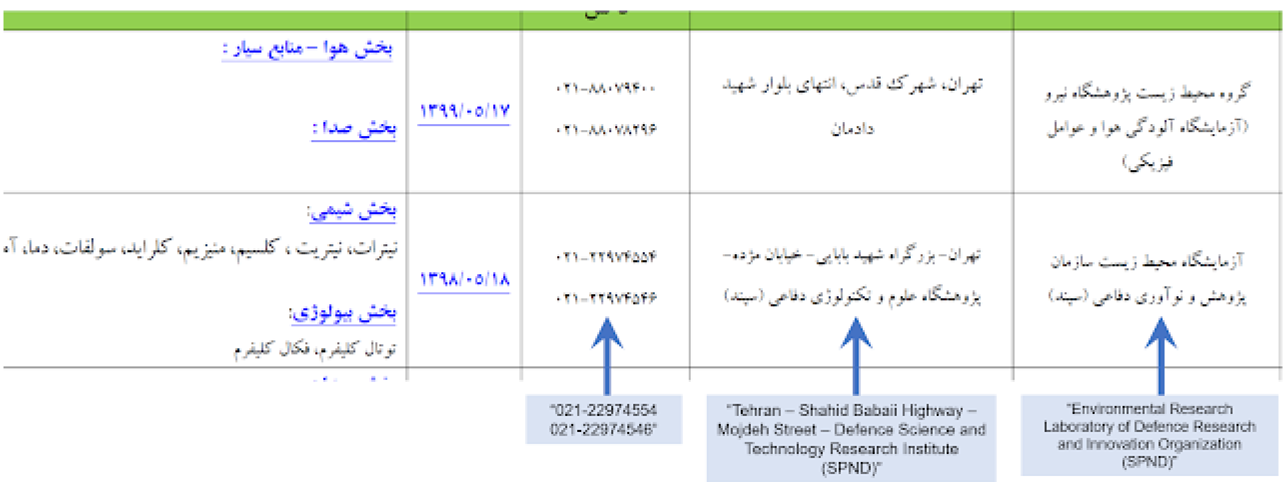
We know from authoritative sources that Dr Rouhollah Ghaderi (national ID 4579489705) is a long-time, senior official of SPND. In March 2019, the US Treasury put Dr Ghaderi under sanctions for directing SPND's Shahid Fakhr Moghadam Group (*گروه شهید فخار مقدم*), one of SPND's main research entities. Shahid Fakhr Moghadam has built explosion simulators and radiation and neutron monitoring and detection system for SPND, according to the Treasury.

The second factor that ties the IAP to SPND are the address and phone number on the document, which - unsurprisingly - just happen to be also used by SPND.

Helpfully for us, the contract is written on an IAP letterhead, and so it has the IAP's address, phone and fax numbers on each page. Here's an example:



And then the phone and fax numbers. It won't surprise you to learn that the IAP phone and fax numbers on that contract are also used by SPND. We know that from health and safety licensing documents released by Iran's Department of Environment, excerpted below:



So what is this contract between IAP and the Islamic Azad University all about?

SPND has a few desperate requirements: money, legitimacy, and access to foreign technology. For SPND, an agreement of cooperation with Islamic Azad University fulfils each of these needs. Amongst other things, the agreement binds IAP/SPND and IAU to collaborate on research projects of mutual interest; mandates that IAP/SPND help procure and fit out IAU laboratories with nuclear-related equipment; and enables IAP/SPND to provide employment to IAU postgraduate students. Through each of these avenues, SPND can hide behind the name of IAU in order to get funding and to procure foreign tech.

We know this because SPND has done it all before with a different university. In the early 2000s, when the IAP wanted to appear respectable, it borrowed the name of another civilian research institution, the Iran University of Science and Technology (IUST - *دانشگاه علم و صنعت ایران*). As an example, here's a research paper authored by the martyred scientist Masoud

Alimohammadi (مسعود علیمحمدی), a key member of Iran's pre-2003 nuclear weapons programme, where he describes his affiliation as the "Institute of Applied Physics, IUST":

Exactly solvable models through the empty interval method, for more-than-two-site interactions

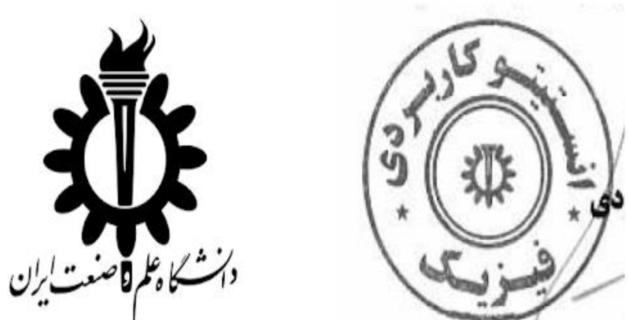
M. Khorrami[a,d1] , A. Aghamohammadi[b,d2] & M. Alimohammadi[c,d3]

[a] *Institute for Advanced Studies in Basic Sciences, P. O. Box 159, Zanjan 45195, Iran.*
[b] *Department of Physics, Alzahra University, Tehran 19834, Iran.*
[c] *Physics Department, University of Tehran, North Karegar Avenue, Tehran, Iran.*
[d] *Institute of Applied Physics, IUST, P. O. Box 16845-163, Tehran, Iran.*

Abstract

Single-species reaction-diffusion systems on a one-dimensional lattice are considered, in them more than two neighboring sites interact. Constraints

The IAP/SPND and IUST might actually still retain some friendly connections, or it could just be that the IAP likes to continue to pretend that it is affiliated with IUST. The IAP's stamp, which we saw on the contract with IAU, even has a version of the IUST torch-and-cog logo on it:



Iran University of Science and Technology logo

Institute of Applied Physics stamp

http://www.iranredline.org/2019/12/the-iap-is-back-and-putting-irans_12.html

۱ و ۲ اسفند ماه ۱۳۹۷ دانشگاه آزاد اسلامی واحد بوشهر
25th Iranian Nuclear Conference
20-21Feb2019 Islamic Azad University
Bushehr Branch
برنامه زمان بندی کنفرانس ۱۳۹۷
شروع ارسال مقالات ۱۳۹۷/۰۴/۰۱
پایان ارسال مقالات ۱۳۹۷/۰۹/۰۱
اعلام پذیرش اولیه مقالات ۱۳۹۷/۱۰/۰۱
آخرین مهلت ارسال مقالات اصلاح شده ۱۳۹۷/۱۰/۱۵
اعلام نهایی پذیرش مقالات ۱۳۹۷/۱۱/۰۱
بیست و پنجمین کنفرانس هسته ای ایران
محورهای کنفرانس:
آشکارسازی و دزیمتری
پدافند غیرعامل هسته‌ای
پرتوپزشکی
پلاسما و همجوشی هسته ای
راکتور و نیروگاه های هسته‌ای
شتاب دهنده های ذرات
فیزیک هسته ای
کاربردپرتوها
مواد و ایزوتوپ‌های پایدار
Institute of Applied Physics,
SPND front organization
حق ثبت نام در کنفرانس :
آزاد ۴/۰۰۰/۰۰۰ ریال
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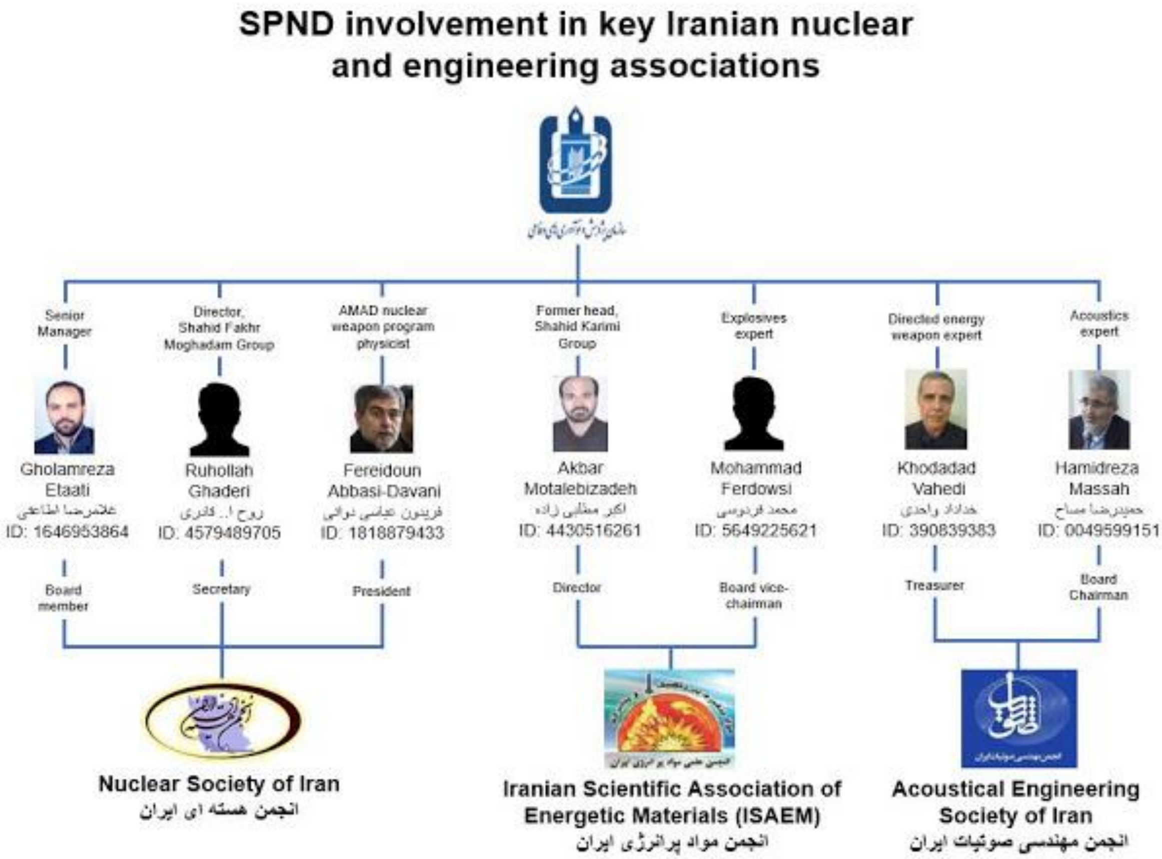
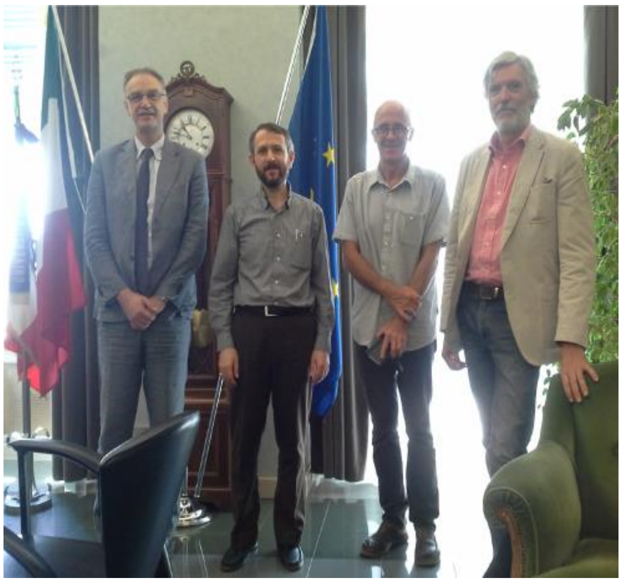


https://www.iranredline.org/2020/11/we-are-village-green-nuclear-weapon.html

SBU and Trieste University agreement

On 5th of August 2015 it was a meeting between president of Trieste University and Vice-chair for researches and technology of physics department of SBU. Accordingly, it was supposed that scientific agreement containing the exchange program for PhD students not only in physics but also in various field of researches of both sides will be started. This agreement has been finalized on August 2016.



Senior Iranian Nuclear Engineer Dr. Mahmoud-Reza Aghamiri: Israeli Threats, Ukraine Crisis, North Korean Behavior Have Taught Us That Iran Needs Deterrence; We Have The Capability To Rapidly Increase Uranium Enrichment To 99% And Install A Nuclear Warhead

#9492 | 03:23, April 9, 2022
Source: The Internet - "snn.ir on Telegram"

Dr. Mahmoud-Reza Aghamiri, the head of the Nuclear Engineering Department at Shahid Beheshti University in Tehran, said in a lecture that was uploaded to the Snn.ir Telegram channel on April 9, 2022, that Iran has nuclear "deterrence capability." He explained that this is the ability to rapidly enrich uranium to 99% and "not control" nuclear fission." He added that Iran has the capability to Install a nuclear warhead "and let it do whatever it wants." He referred to this as Iran's "inalienable right," gave North Korea as an example of the effectiveness of nuclear deterrence, explaining that it can threaten America and act like a bully even though it only has seven nuclear bombs.

Appendix C: The Thesis Advsors

Masoud Askari

Emeritus professor of materials science and engineering Sharif University of Technology
Verified email at sharif.edu

Mohammad Nusheh

Lead R&D Scientist and co-founder at Hot Lime Labs

Islamic Azad University, Iran

Mohammad Nusheh received his B.S. (2002), M.Sc. (2005) and Ph.D. (2010) degrees in Extractive Metallurgy from Department of Materials Science and Engineering at Sharif University of Technology in Iran. After working as a Researcher at Institute of Multidisciplinary Research in Advanced Materials at Tohoku University in Japan, Dr. Nusheh joined the Islamic Azad University of Zanjan, as an Assistant Professor. He has published several papers in academic journals and conference proceedings. He received Khwarizmi Young Award for his contributions in R&D of a new technology related to the extraction of magnesium metal. The scientific activities of Dr. Nusheh cover various fields such as non-ferrous and nano-sized materials processing industries; various processing routes such as hydro and pyrometallurgical processing and recycling.

Education

Sharif University of Technology

PhD, Extractive Metallurgy, 2006 - 2010

Ali Asghar Alamolhoda

Physics Department, University of Tehran and Institute of Applied Physics, Iran University of Science and Technology (Author's private files on the Institute of Applied Physics)

Director, Institute of Water and Energy, Sharif University of Technology | SHARIF

Secretariat of Desalination Committee, Ministry of Science and Technology
Secretary of the Water Affairs Committee of the Iranian Vice President's Office
Possible relationship Cleric Ahmad Alamolhoda, who is the Friday prayer Imam of Mashhad

Professor Ali Asghar Alamolhoda of Sharif University of Technology in Iran visited ISL

Update time：2017-12-04

On November 29-30, Professor Ali Asghar Alamolhoda, director of the Institute of Water and Energy Research at Sharif University of Technology in Iran, visited ISL (Qinghai Institute of Salt Lakes)

Professor Alamolhoda visited the science and technology exhibition hall, analysis and testing department and some laboratories to learn more about the history, subject layout, research fields, and specific scientific research work of ISL.

Wu Zhijian, the deputy director of the presiding work, hosted the forum and related personnel attended the forum. Wu Zhijian welcomed Professor Alamolhoda's visit and thanked him for promoting bilateral cooperation. Prof. Alamolhoda concurrently served as Secretary of the Water Affairs Committee of the Iranian Vice President's Office. He described in detail Iran's desalination, desalination of salt water, protection and utilization of salt lake resources, sewage treatment, renewable energy development, etc., and introduced Iran's scientific and technological needs in related fields. . Dr. Ma Xiaomin from the Chinese Academy of Sciences Literature and Information Center, who introduced the cooperation between the Chinese Academy of Sciences and Iran, and the construction and operation of the joint research center for water and environment in Iraq.

Prof. Alamolhoda described technological needs in related fields in Iran.

Wu Zhijian chaired the forum.

Prof. Alamolhoda visited the laboratory

http://english.isl.cas.cn/ns/es/201806/t20180604_193829.html

Mohammad Outokesh

Associate professor of Energy Engineering, Sharif Uinversity of Technology, Tehran, Iran
Verified email at sharif.edu

- **Study on Thermodynamics of Iodine Vapor Adsorption on Cu Nanoparticles by Different Computational Approach**

  , M.Sc. ThesisSharif University of TechnologyRazavi, Maliheh (Author) ; Outokesh, Mohammad (Supervisor)
  Abstract
  - مح تواي ک تاب

- **Synthesis and Characterization of Graphene-based Material and Investigation of its Adsorption Properties for Radioactive Waste**

  , Ph.D. DissertationSharif University of TechnologyTayyebi, Ahmad (Author) ; Outokesh, Mohammad (Supervisor)
  Abstract
  - مح تواي ک تاب

- **Separation of Boron Isotopes by Distillation of (CH3)2O-BF3 Complex**

  , M.Sc. ThesisSharif University of Technologyabdollahi, Mojtaba (Author) ; Outokesh, Mohammad (Supervisor) ; Ahmadi, Javad (Supervisor)
  Abstract
  - مح تواي پ ايان نامه

- **Study of Mechanism of Formation of Metal Oxide Nanoparticles in Supercritical Water Medium**

  , M.Sc. ThesisSharif University of TechnologyAkhlaghpasand, Hamze (Author) ; Outokesh, Mohammad (Supervisor) ; Ahmadi, Javad (Co-Advisor)
  Abstract
  - مح تواي ک تاب

Synthesis Deuterated Aromatic Compunds by Supercritical Method

, M.Sc. ThesisSharif University of TechnologyShadjirati, Yasamin (Author) ; Outokesh, Mohammad (Supervisor) ; Sajadi, Soudeh (Supervisor)
Abstract

- مح تواي ک تاب

Lithium Isotopes Separation by Amalgam Electrolysis Method

, M.Sc. ThesisSharif University of TechnologyAryanpur, Vahid (Author) ; Outokesh, Mohammad (Supervisor) ; Ahmadi, Javad (Supervisor)
Abstract

- مح تواي پ اي ان ن امه

Lithium Isotopes Separation by Electrolysis Amalgam by a Continuous Method

, M.Sc. ThesisSharif University of TechnologyKowsari, Mohammad Reza (Author) ; Outokesh, Mohammad (Supervisor) ; Ahmadi, Javad (Co-Advisor)
Abstract

- مح تواي ک تاب

Synthesis and Functionalization of Graphene for Uranium Adsorption

, M.Sc. ThesisSharif University of TechnologyBashardoust, Mahyar (Author) ; Outokesh, Mohammad (Supervisor) ; Khanchi, Alireza (Supervisor)
Abstract

- مح تواي ک تاب

Synthesis and Fuctionalization of Graphene oxide for Thorium Adsorption

, M.Sc. ThesisSharif University of TechnologyDoram, Amir (Author) ; Outokesh , Mohammad (Supervisor) ; Ahmadi, Javad (Supervisor)
Abstract

- مح تواي ک تاب

Synthesis of Graphene and Graphene Oxide and It’s Applications for Adsorption of Iodine

, M.Sc. ThesisSharif University of TechnologyRizehkar, Sevda Sadat (Author) ; Outokesh, Mohammad (Supervisor) ; Khanchi, Alireza (Supervisor)
Abstract

- مح تواي ک تاب

Derivation of a Scalable Mass Ttransfer Equation for Adsorption of Uranium on Resin in Stirred Reactors

, M.Sc. ThesisSharif University of TechnologyNaderi, Ali (Author) ; Outokesh, Mohammad (Supervisor) ; khanchi, Alireza (Supervisor)
Abstract

- مح تواي پ اي ان ن امه

Experimental Study and Optimization of Nuclear Grade Boric Acid Production Process

, M.Sc. ThesisSharif University of TechnologyAhmadian Koudakan, Payam (Author) ; Outokesh, Mohammad (Supervisor) ; Aflaki Pashaki, Fereydoon (Supervisor)
Abstract

- ي ک تابمح توا

Preparation of High Purity BF3 Gas and Feasibility Study on Separation of Boron Isotopes by its Injection into a Gas Centrifuge

, M.Sc. ThesisSharif University of TechnologyHashemi Baragoori, Keyvan (Author) ; Outokesh, Mohammad (Supervisor) ; Karimi-Sabet, Javad (Supervisor)
Abstract

- مح تواي ک تاب

Synthesis of Graphene by New Methods, and its Application for Adsorption of Cobalt

, M.Sc. ThesisSharif University of TechnologyFaham Mofrad, Ali (Author) ; Outokesh, Mohammad (Supervisor) ; Shafiekhani, Azizollah (Supervisor)
Abstract

- مح تواي ک تاب

Synthesis of Graphene and its Application for Adsorption of Cobalt and Strontium Ions, and as an Electrode in Electrochemical Cells (Battery)

, M.Sc. ThesisSharif University of TechnologyJalilzadeh, Hassan (Author) ; Outokesh, Mohammad (Supervisor) ; Hosseinpour, Morteza (Co-Supervisor)
Abstract

- مح تواي ک تاب

Study on the Performance of Magnetic Nanoparticles in Hyper-thermic Treatment of Cancerous Tumors, by Heating an MRI Apparatus

, M.Sc. ThesisSharif University of TechnologyPayami Golhin, Zahra (Author) ; Outokesh, Mohammad (Supervisor) ; Nourani, Mohammad Reza (Supervisor)
Abstract

- مح تواي ک تاب

Synthesis of Gold Nanoparticles and Study on Their Applications as a Catalyst and as a Carrier for the Radiomedicines

, M.Sc. ThesisSharif University of TechnologyEskandari, Najmeh (Author) ; Outokesh, Mohammad (Supervisor) ; Ahmadi, Javad (Supervisor) ; Sadjadi, Soude (Co-Advisor)
Abstract

- مح تواي ک تاب

Synthesis of Platinum Nanoparticles and Study on its Application as a Catalyst and an Adsorbent of the Radioactive Elements

, M.Sc. ThesisSharif University of TechnologyMehdizadeh, Sofia (Author) ; Outokesh, Mohammad (Supervisor) ; Ahmadi, Javad (Supervisor) ; Sadjadi, Sodeh (Co-Advisor)
Abstract

- محتواي پايان نامه

Study on Continuous Phase Holdup in a Pulsed Disc and Doughnut Extraction Column by Radiotracer Technique

, M.Sc. ThesisSharif University of TechnologyYaghoubi, Yaser (Author) ; Outokesh, Mohammad (Supervisor) ; Tabasi, Mohsen (Supervisor) ; Mostaedi, M.T (Co-Advisor)
Abstract

- محتواي کتاب

Study on Separation of Uranium from Phosphoric Acid by Column Chromatography

, M.Sc. ThesisSharif University of TechnologyGrayeli, Fatemeh (Author) ; Sohrabpour, Mostafa (Supervisor) ; Khanchi, Ali Reza (Supervisor) ; Outokesh, Mohammad (Supervisor)
Abstract

- محتواي پايان نامه

Production of Uranium Dioxide Nano Powder With Hydrothermal Method in Supercritical Water Reactor

, M.Sc. ThesisSharif University of TechnologyGolzary, Abooali (Author) ; Outokesh, Mohammad (Supervisor) ; Ahmadi, Javad (Supervisor) ; Karimi Sabet, Javad (Co-Advisor)
Abstract

- محتواي پايان نامه

Study on the Mass Transfer and Isotope Separation Phenomena in a Gas Centrifuge by Using FEREON Mixtures as Model Compounds

, M.Sc. ThesisSharif University of TechnologyFard Kashani, Mohammad Reza (Author) ; Outokesh, Mohammad (Supervisor) ; Karimi-Sabet, Javad (Supervisor) ; Norouzi, Ali (Co-Advisor)
Abstract

- محتواي کتاب

Adsorption Of Uranium from Phosphoric acid and Waste Water with Microcapsules Contains Selective Extractants

, M.Sc. ThesisSharif University of TechnologyTayebi, Ahmad (Author) ; Ghofrani, Mohammad Bagher (Supervisor) ; Khanchi, Alireza (Supervisor) ; Outokesh, Mohammad (Co-Advisor)
Abstract

- محتواي پايان نامه

Fabrication of “Boron-Clay-Polymer" and "Lead-Clay-Polymer" Nanocomposites for Radiation Shielding of Neutron and Gamma Rays

, M.Sc. ThesisSharif University of TechnologyKiani, Mohammad Amin (Author) ; Outokesh, Mohammad (Supervisor) ; Ahmadi, Javad (Supervisor) ; Mohammadi, Agheil (Co-Advisor)
Abstract

- محتوای کتاب

Investigation on the Ability of Pseudomonas Putida Bacterium for Biosorption of Se(IV) from the Aqueous Solutions

, M.Sc. ThesisSharif University of TechnologyEsmaeili Doabsari, Fatemeh (Author) ; Outokesh, Mohammad (Supervisor) ; Keshtkar, Alireza (Supervisor) ; Sohbatzadeh, Hozhabr (Co-Supervisor)
Abstract

- محتوای کتاب

Investigation of the Optimum Conditions for the Regeneration of Anion and Cation Exchange Resins of the TR System of Bushehr Nuclear Power Plant

, M.Sc. ThesisSharif University of TechnologyArkannia, Mohammad Hossein (Author) ; Outokesh, Mohammad (Supervisor) ; Seyed Kalal, Hossein (Supervisor) ; Habibian, Alireza (Co-Supervisor)
Abstract

- محتوای کتاب

Thermal-hydraulic Analysis of Dry Storage Cask of the Spent Nuclear Fuel and Construction of a Prototype Experimental Setup for its Simulation

, M.Sc. ThesisSharif University of TechnologyHejazi, Mohammad Ali (Author) ; Outokesh, Mohammad (Supervisor) ; Mousavian, Khalil (Supervisor) ; Rezaeian, Mahdi (Co-Supervisor)
Abstract

- محتوای کتاب

Hydrothermal Synthesis of Copper (II) Oxide Nanparticles at Supercritical Conditions and Their Application in Decantamination of Tritium Polluted Streams

, M.Sc. ThesisSharif University of TechnologyHosseinpour, Morteza (Author) ; Ghofrani, Mohammad Bagher (Supervisor) ; Ahmadi, Javad (Supervisor) ; Outokesh, Mohammad (Co-Advisor) ; Mosavand, Tahereh (Co-Advisor)

- محتوای پایان نامه

Experimental Study of Molybdenum Extraction Process in an Oldshue-rushton Extraction Column

, M.Sc. ThesisSharif University of TechnologyShakib, Benyamin (Author) ; Outokesh, Mohammad (Supervisor) ; Torab- Mostaedi, Mesam (Supervisor) ; Asadollahzadeh, Mehdi (Co-Supervisor)
Abstract

- محتوای کتاب

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M.Sc.**:** Lithium Isotope Separation in Castner-Kellner Cell by Electrolysis Amalgam System by a Continuous Method
B.Sc**.:**Simulation of the Sugar Process Manufacturing with Aspen-Plus Software

Conference Presentations:

M.R. Kosari, S.j. Ahmadi, M. Outokesh, j. Rafee, “Lithium Isotopes Enrichment in order to Production of ^{6}Li isotope as Elementary Material in Fusion”, The 3rd National Conference on New Technology of Chemistry and Chemical Engineering, Islamic Azad Universitry,Ghochan, Iran, (2014).

M.R. Kosari, M. Outokesh, S. j. Ahmadi, j. Rafeei, A. Aminian, “Application of Lithium Isotopes and their Separation Method”, The 1st National Conference on Application of Stable Isotopes, Science Department, Ferdowsi University,Mashhad, Iran, (2013).

M.R. Kosari, S.j. Ahmadi, M. Outokesh, A. Aminian, j. Rafeei, “Study on Efficiency of Electrolysis System for Lithium Isotope Separation”, The 1st National Conference on Application of Stable Isotopes, Science Department, Ferdowsi University,Mashhad, Iran, (2013).

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Appendix D: Selected Foreign lithium-6 separation science and technology

Both the declassified and open source literature was reviewed and relevant articles and documents relating to lithium isotope separation techniques were retrieved. Only those articles and documents that were deemed most relevant are sited.

Amalgam and Chemical Exchange Systems

United States

Before the beginning of World War II researchers in the United States investigated the separation of lithium isotopes using both electrolytic and chemical exchange methods.[1]

In the early 1950s the US Atomic Energy Commission decided to have the ability by the chemical exchange process "of concentrating any or all of the isotopes of the lighter elements of the periodic table through calcium".[2]

An Oak Ridge report describing a systematic effort to develop a liquid-liquid system suitable for the separation of lithium isotopes was written in 1951 and declassified in early 1957. Despite investigating numerous systems "no measurable isotopic enhancement was found in any of the systems studied".[3] Later research efforts concentrated on ion-exchange chromatography, molecular distillation, and two-phase equilibrium systems.[4]

The most successful of these processes studied was the two-phase equilibrium systems. "By the first part of 1953, the program for the separation of lithium isotopes by chemical methods had expanded and matured to such a point that it was believed an interim report condensing the chemistry under one cover would be advantageous….Experimental data from all of the systems investigated for the chemical separation of lithium isotope have shown the separation factor to be a marked function of temperature. For this reason it is possible to consider a unique method achieving reflux known as dual temperature process. This process has maximum utility when it is possible to operate an exchange system between two widely separated temperautres".[5]

According to a Union Carbide report "several hundred systems to separate lithium isotopes using organic/organic or organic/aqueous systems in place of mercury and water were investigated in order to avoid the use of large quantities of mercury, but no other systems of practical significance were found. Of the chemical methods investigated, only lithium amalgam with lithium hydroxide or compounds dissolved in organic solvents appeared to be practical systems for use in the separation of lithium".[6]

The process that was developed as the result of this research became known as Colex (column exchange). The process has been described as follows "A lithium-mercury amalgam is first prepared using the natural material. The amalgam is then agitated with a lithium hydroxide solution prepared from natural lithium. The desired lithium-6 concentrates in the amalgam and the more common lithium-7 migrates to the hydroxide. A counter flow of amalgam and hydroxide passes through a cascade of stages until the desired enrichment is reached. After enrichment, the lithium-6 was transformed from the amalgam phase and converted to lithium hydroxide. This lithium was then converted from hydroxide to chloride, to the metal, and finally to the deuteride. Pulverized lithium deuteride was shaped by pressing, machined, canned in stainless steel, and assembled into thermonuclear components…. It was found that the elimination of oxygen gas imparted stability to the amalgam to allow contact between the two phases without serious amalgam decomposition".[7]

United Kingdom

Important details of the research on lithium isotope separation that British scientists studied are reviewed in a working paper from the Mountbatten Centre for International Research.[8] "At Harwell, Lacey wrote a report in 1954 on isotope separation, favoring the amalgam method.

The report closely followed the Lewis and Macdonald method methods, in which droplets of an amalgam of lithium in mercury fell down a vertical column 18m high and 4mm in diameter. A solution of lithium chloride in alcohol passed up the tube. An isotope exchange took place between the two lithium media and the amalgam reaching the bottom of the column is enriched in Li6.[9]

Lacey later settled on using an aqueous solution of lithium hydroxide instead of the lithium chloride dissolved in alcohol described in the Lewis and Macdonald paper. The amalgam process that Lacey sketched out "used a vertical amalgam exchange column 14ft high. To achieve the necessary separation, many columns would have to be operated in a cascade. The height of the column implies that pumps would be required to handle mercury at a pressure of some 6 atmospheres and it is understood that this presented practical difficulties.[10]

At Capenhurst, Clark and Whitehead experimented with a mixer-settler system and so avoided the problems produced by the large head of mercury in the column exchange method. In this system the amalgam and aqueous solution are agitated together. The mixture is then passed to a settler tank, where the amalgam, now enriched in the lighter lithium isotope, settles to the bottom".[11]

USSR

A few journal articles were found on lithium isotope separation in amalgam and chemical exchange.[12] Most of this work was done at the Mendeleev Institute of Chemical Engineering located in Moscow.

China

The only useful information on lithium isotope in amalgam and chemical exchange systems comes in a 2011 review done by the School of Chemistry and Material Engineering, Jiangnan University, Wuxi, China.[13] Additional information from Chinese literature sources is available but is not reported on here.

China has also done a great detail of research into the use benzo-15-crown-5 ethers for lithium isotope separation.[14] In a series of articles the abstract of one states "A green and efficient liquid–liquid extraction system was developed for the separation of lithium isotopes by using hydrophobic ionic liquids (ILs = $[C_{4,6,8,10}mim]^+[NTf_2]^-$) as extraction organic phase and benzo-15-crown-5 (B15C5) as complexing agent. The maximum single-stage separation factor α of $^6Li/^7Li$ obtained in this study was 1.029 ± 0.001, indicating ^6Li was enriched in ionic liquid phase while ^7Li was concentrated in the aqueous phase. The lithium ion was extracted into the ionic liquid in the formation of 1:2 complex $[Li^+(B15C5)_2]$. The negative data of thermodynamic parameters (ΔH^0 and ΔG^0) suggest that the extraction system was a spontaneous exothermic process. In addition, effective lithium isotopes separation factor and the extraction efficiency of lithium ions can be gained in the condition of lower temperature with softer counter anions in the novel extraction system".

France

"The fundamental separation factors of some processes are investigated: the distillation of metallic lithium, counter current electromigration in fused salts (particularly in lithium nitrate), electrolysis in aqueous solution and ion exchange. The chemical transfer between a lithium amalgam and lithium salts in a dimethylformamide solution (a solvent which is not attacked by the amalgam) is also studied.[15]

India

Researchers at the Bhabha Atomic Research Centre (BARC) reported that "Isotope effects in ion-exchange equilibria in aqueous and mixed solvents are analyzed in terms of the general features of ion-exchange equilibria and of isotope effects in chemical equilibria. The special role of solvent fractionation effects in ion-exchange equilibria in mixed solvents is pointed out. The experimental data on lithium isotope effects in ion-exchange equilibria in mixed solvents are shown to conform to the above situations".[16]

Iraq

Iraqi research focused on both the techniques of solvent extraction and ion exchange chromatography for the separation of lithium isotopes. "Results in July 1989 favored the system crown ether-solvent extraction chemical exchange system. Parameters required for the pilot plant design were planned to be realized by October 1990….Based on a squared off cascade, calculations were made for 10kg/year and 100kg/year prototype plants of 99%^{6}Li to be constructed at Tuwaitha. Experiments were conducted at site Tuwaitha (Bldg. 90), on a RAC column, and on three laboratory mixer settler batteries to study the hydrodynamics and stability of the chemical exchange system. An enrichment factor of around 1.03 was obtained experimentally."[17]

Japan

"The elementary separation factors for lithium isotopes in the isotope-exchange equilibria between the amalgam and the organic solution have been measured at several temperatures between -15 and 85C. DMSO, DMA, and DEF were employed as the organic solvents for lithium salts. The separation factors with these systems have been found to be larger than reported previously with other chemical exchange systems….The large separation factors obtained in these experiments indicate that the present isotope-exchange process may be suitable for the enrichment of lithium isotopes”.[18]

Later research examined the “Isotope effects in the lithium amalgam formation were studied by using the mercury cathode and LiOH solutions… Higher efficiency of electrolytic amalgam formation was observed at higher LiOH concentrations and higher applied voltages….From the isotopic analyses on the samples taken during the electrolysis, it was found that the isotopic equilibrium was attained between the aqueous and the liquid amalgam phases”.[19]

Brazil

A 1998 thesis provided experimental details on the separation of isotopes of lithium by electrolytic amalgamation. “An electrolytic cell with a confined cathode was used to obtain data for the design of a separation stage…The initial work was followed by the design of a moving mercury cathode electrolytic cell and three experiments with six batches stages were performed for the determination of separation factor…In view of the results obtained, a five stages continuous scheme was proposed”.[20]

Romania

Detailed experiments on the separation of lithium isotopes by countercurrent exchange between lithium-amalgam and aqueous LiOH have been carried out since at least 1976. Work reported on in 1999 described a separation capacity over column as being 570 mol swu/year and they “believed that column with at least 200 times greater capacity may be realized”.[21]

Pakistan

Pakistan has published a number of journal articles that deal with using the laser isotope separation method for separation of lithium-6. A brief mention of uranium AVLIS research can be found in a referenced journal article.[22]

According to Mansoor Ahmed a major laser research facility was established at PINSTECH by British-trained Pakistani scientists.[23]

Israel

Israeli scientists from their nuclear research have claimed to have enriched lithium-6 in decagram quantities.[24]

North Korea

A 2017 article provided the first scientific details regarding North Korea’s lithium-6 isotope separation research.[25] Additional details on North Korea’s research in this can be found in a 2018 journal article.[26]

North Korean authors from the Faculty of Power Engineering, Kim Chaek University of Technology recently published a journal that looks at the "Simultaneous selective laser pumping of lithium…In this paper, possibly of more effective isotope separation by simultaneous pumping of two isotopes is considered against usual methods that pumps only one isotope for lithium isotope separation. It gets to obtain two enriched materials without depleted material by a single optical pumping…It is necessary method in case that enriched material of both isotopes are useful such as lithium. The next step will be a first experimental demonstration of this."[27]

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