

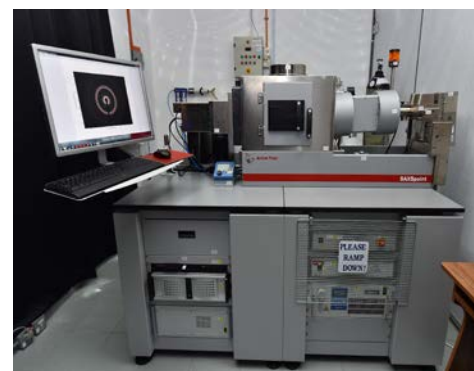
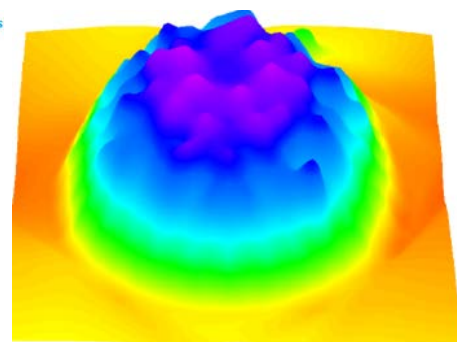
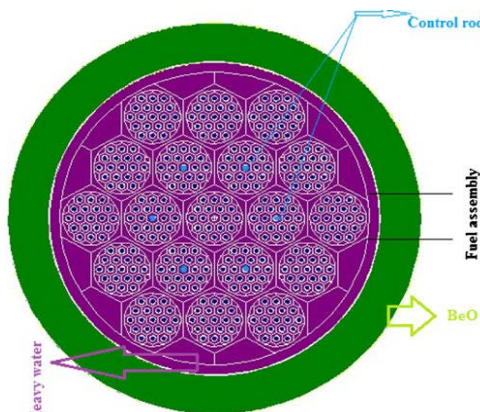
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EDITORIAL

After working hard by the editorial members, the issue of Vol. 21 of BNM is finally published. The editorial would like to apologize to all contributors and readers for patiently waiting and loyally supporting of the BNM new issue. This effort has to be appreciated and we hope this spirit will continue for the live of MNS and BNM in particular.

We know that the issue of BNM needs very strong support and commitment from all members of MNS and readers in general. The editorial is very optimistic, with the good support and enough articles from the contributors the half yearly issue of this bulletin will be published on schedule. We also see that from the past few years there was encouraging response from contributors of other organizations beside Nuclear Malaysia. This can probably be improved in the future as sharing and disseminating knowledge is one of the agendas of our society. Authors could deliver the same message but probably from a different approach. The editorial would also like to welcome contribution from student at levels of education and the MNS has agreed to provide some token as an incentive for your efforts.

The editor welcome articles and news from any related science, technology, engineering regulatory and economy issues. However, we should be bear in mind that the nuclear and nuclear related articles and news should reflex the title of this bulletin. With the current scenario and trend of world energy demand, food and water security, environmental concerned, it is hoped that articles and news related to nuclear and nuclear related issue, in particular could be a "hot" topic of discussion.

Chief Editor***Buletin Nuklear Malaysia, October 2023***

The editor welcome articles and news from any related science, technology, engineering regulatory and economy issues. However, we should be bear in mind that the nuclear and nuclear related articles and news should reflex the title of this bulletin. With the current scenario and trend of world energy demand, food and water security, environmental concerned, it is hoped that articles and news related to nuclear and nuclear related issue, in particular could be a „hot “topic of discussion.

INOVASI PENGESAN IMEJ RADIOGRAFI BERASASKAN KAMERA

Julie Andrianny Murshidi, Khairiah Yazid, Azraf Azman dan Rafhayudi Jamro

Agensi Nuklear Malaysia, Komplek PUSPATI, Bangi, 43000 Kajang, Selangor.

KANGAR: Pasukan Alur Neutron, Agensi Nuklear Malaysia berjaya merangkul pingat perak bagi kategori CROWN dengan memperkenalkan pengesan digital; *MyFlexiDet* pada Pertandingan Inovasi, Reka Bentuk dan Artikulasi Antarabangsa Keenam 2023 (i-IDEA2023). CROWN adalah inovasi kategori Professional di i-IDEA™. Ia membolehkan individu / pasukan / syarikat mempercepat budaya inovasi dengan menjana idea-idea baru dan kaedah berinovatif dalam menyelesaikan masalah yang mungkin atau memberi kesan kepada perniagaan atau organisasi. Acara ini yang diadakan sekali dalam dua tahun (acara dwitahunan) merupakan acara utama i-IDEA™. Ia terbuka untuk inovator, ahli akademik dan usahawan dari seluruh dunia.

Kemenangan pasukan alur neutron itu diperolehi melalui kerjasama Bahagian Sokongan Teknikal dan Bahagian Teknologi Industri diketuai oleh Puan Khairiah Yazid dan tiga pegawai penyelidik kanan yang lain iaitu Encik Azraf Azman, Dr. Julie Andrianny Murshidi dan Encik Rafhayudi Jamro.

Puan Khairiah berkata, mereka tampil dengan inovasi yang dikhususkan untuk menaik taraf sistem neutron radiograf digital dan membangunkan instrumen pengimejan canggih iaitu tomografi berkomputer berkembar sinar-X dan neutron. Neutron radiografi merupakan satu teknik tanpa musnah digunakan untuk analisa struktur dalaman sesuatu komponen / sampel di mana kebolehppercayaan amat penting.



Katanya, kos satu set pengesan digital adalah mahal dan perlu dibeli dari luar negara. Tambahan pula pada masa ini peruntukan untuk menjalankan penyelidikan dan pembangunan amat terhad. Atas sebab ini, pasukan alur neutron mengambil inisiatif untuk berinovasi dan memasang pengesan digital secara dalaman dan menggunakan komponen sedia ada. Pengesan digital baharu yang dipanggil *MyFlexiDet* ini bersifat fleksibel, di mana ia boleh digunakan untuk sinaran neutron mahupun sinaran-X.

"Ciri utama inovasi yang dicipta dan direkabentuk oleh Khairiah ialah kamera dan skrin penukar (*converter screen*) yang boleh ditukar berdasarkan aplikasi. Ia datang dengan program dalaman untuk mengawal pemerolehan imej. *MyFlexiDet* ini bukan sahaja boleh digunakan di reaktor TRIGA PUSPATI (RTP) tetapi boleh juga digunakan untuk aplikasi pengimejan industri yang menggunakan sinar-X," katanya.

Pertandingan i-IDEA2023 ini dianjurkan oleh UiTM Cawangan Perlis dari 9 hingga 11 Mei 2023 lalu bertemakan 'Memperkasakan Penyelidikan, Idea Inovasi dan Keusahawanan ke Arah Ekonomi Mampan'.

Sebanyak 227 produk inovasi dihasilkan oleh ahli akademik dan bukan akademik, penyelidik, pelajar Institusi Pengajian Tinggi (IPT) tempatan dan luar negara serta sekolah-sekolah menengah seluruh negara.

Lawatan Sambil Belajar Pelajar Kejuruteraan UNITEN ke Reaktor TRIGA PUSPATI

Nurhayati Ramli

Agensi Nuklear Malaysia, Komplek PUSPATI, Bangi, 43000 Kajang, Selangor.

Pusat Teknologi Reaktor (PTR) memainkan peranan yang penting di dalam mengendalikan lawatan ilmiah ke Reaktor TRIGA PUSPATI (RTP) bagi meningkatkan kefahaman para pelawat berkaitan reaktor fizik, kejuruteraan reaktor, rekabentuk fasiliti, perlindungan sinaran dan lain-lain perkara yang berkaitan. Para pelawat RTP datangnya dari pelbagai agensi kerajaan dan swasta, institusi pengajian tinggi serta sekolah-sekolah di seluruh negara.

Pada 14 Julai 2022, RTP telah menerima lawatan dari para pelajar Fakulti Kejuruteraan, Universiti Tenaga Nasional (UNITEN). Lawatan ini telah dirancang untuk 33 orang pelajar iaitu 19 orang pelajar dari Jabatan Kejuruteraan Kuasa, 12 orang pelajar dari Jabatan Kejuruteraan Mekanikal, 1 orang pelajar dari Jabatan Kejuruteraan Elektrik dan Elektronik dan 1 orang pelajar dari Jabatan Kejuruteraan Awam.



Para pelajar Fakulti Kejuruteraan UNITEN bergambar bersama kakitangan PTR.

Tujuan lawatan sambil belajar ini ialah untuk memberi pendedahan kepada para pelajar berkaitan prosedur kendalian RTP. Aktiviti *"RTP Operation Checklist & Reactor Power Control for Operation"* membantu para pelajar memahami dengan lebih baik mengenai struktur, sistem dan komponen (SSC) utama RTP. Selain itu, para pelajar didedahkan dengan prosedur keselamatan semasa RTP dikendalikan. Para pelajar telah dibahagikan kepada tiga kumpulan bagi memastikan sesi lawatan sambil belajar ini dapat dilaksanakan dengan lebih berkesan.

Pihak PTR mengucapkan terima kasih kepada pensyarah Jabatan Kejuruteraan Mekanikal UNITEN, Dr. Nuraslinda Anuar dan Cik Madihah Mujaini di atas lawatan pada kali ini. Penghargaan yang tidak terhingga kepada *Malaysian Nuclear Society* (MNS) di atas kerjasama dan sokongan yang diberikan. Adalah diharapkan lebih banyak institut pengajian tinggi awam atau swasta akan mengadakan lawatan

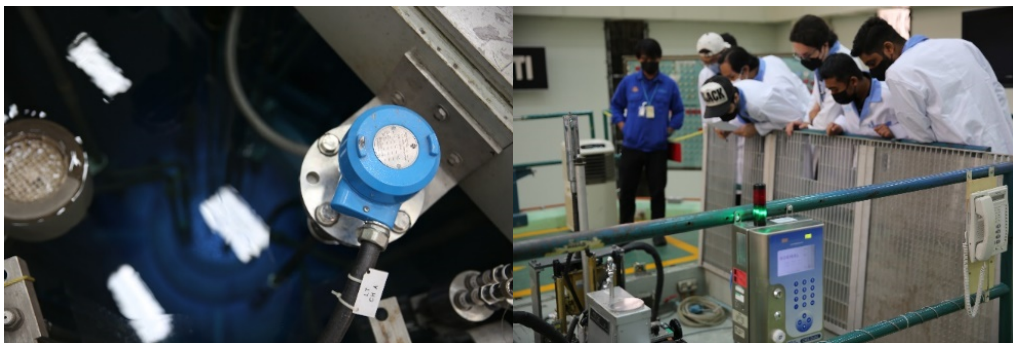
ke RTP pada masa akan datang bagi menambah pengetahuan berkaitan teknologi reaktor.



Taklimat keselamatan dan pembahagian kumpulan.



Penerangan berkaitan SSC di pelantar reaktor (kiri) dan Sistem Penyejukan Primer (kanan).



Para pelajar berpeluang melihat *Cherenkov Effect* semasa RTP sedang beroperasi.

PENGANJURAN INUSTEC 2022, MENJAYAKAN MATLAMAT PEMBANGUNAN LESTARI APLIKASI NUKLEAR

oleh:

**Azlan Shah Mustafa, Dr. Nurul Nafiqah Itam Sulaiman, Siti Hamizah Samsudin,
Munira Hasan**

Pusat Penyelidikan Teknologi Nuklear (NUKLEAR), Universiti Kebangsaan Malaysia (UKM), Bangi, Selangor.

International Nuclear Science, Technology and Engineering Conference 2022 (iNuSTEC2022), dan *Nuclear Youth Competition 2022 (NYC2022)* telah diadakan pada 25 hingga 27 Oktober 2022 di Universiti Kebangsaan Malaysia (UKM), Bangi, Selangor. Program ini adalah anjuran *Malaysian Nuclear Society (MNS)* dengan kerjasama Pusat Penyelidikan Teknologi Nuklear (NUKLEAR), Fakulti Sains dan Teknologi (FST), UKM. Majlis pembukaan persidangan telah dirasmikan oleh Dekan FST UKM, YBrs. Prof. ChM. Dr. Ishak Ahmad.



Tetamu kehormat yang hadir ke majlis perasmian pembukaan iNuSTEC2022.

Pada tahun ini, UKM telah dipilih sekali lagi sebagai tuan rumah penganjuran iNuSTEC. Pemilihan UKM sebagai tuan rumah ini secara tidak langsung akan membawa nama UKM ke persada dunia sebagai salah satu universiti yang menawarkan bidang sains nuklear. Persidangan yang bertemakan 'Aplikasi Nuklear untuk Kejayaan Matlamat Pembangunan Lestari (*Nuclear Application for the Success of the Sustainable Development Goals, SDGs*)' ini adalah persidangan antarabangsa yang memberi peluang kepada para penyelidik membentangkan hasil penyelidikan masing-masing untuk dikongsi bersama peserta tempatan dan antarabangsa. Tambahan pula, persidangan ini juga merupakan salah satu platform bagi pertukaran idea dan pengalaman di antara peserta supaya dapat menghasilkan penyelidikan yang lebih berinovasi dan berguna kepada negara. Persidangan ini juga dapat meningkatkan kesedaran betapa pentingnya sains dan teknologi nuklear demi pembangunan dan kemajuan negara Malaysia, khususnya dalam mendukung hasrat menjadikan Malaysia sebagai negara maju.



Dekan FST UKM, Prof ChM. Dr. Ishak Ahmad menerima cenderahati daripada Presiden MNS Dr. Abdul Aziz selepas perasmian iNuSTEC2022.



Para peserta bergambar bersama selepas majlis perasmian iNuSTEC2022.

Sehingga kini, MNS telah berjaya meletakkan iNuSTEC di peringkat antarabangsa apabila program anjurannya telah dihadiri oleh mereka yang terlibat dalam bidang nuklear dari dalam dan luar negara. Justeru, iNuSTEC telah menjadi pentas untuk mengumpulkan individu-individu yang aktif dan mempunyai kepakaran dalam bidang ini bagi mengetengahkan hasil kajian mereka, seterusnya meningkatkan kerjasama yang lebih global dan menyeluruh.



Prof. Faizal Mohamed menyerahkan cenderahati kepada penceramah ucapnama Prof. Shahidan Radiman dari UKM.

Edisi tahun 2022, iNuSTEC telah membuat jaringan dan kerjasama dengan beberapa persatuan sains nuklear dari Jepun, Korea, dan juga Asia *Oceana Neutron Scattering Association* (AONSA). Selain itu, individu dan organisasi penting dalam bidang ini dari luar negara juga telah menyertai persidangan ini, seperti *Tokyo Institute of Technology* (Tokyo Tech), *Seoul National University* (SNU), dan *Pohang University of Science and Technology* (POSTECH).

Mengikuti tradisi persidangan ini, iNuSTEC dijalankan serentak dengan Nuclear Youth Competition, yang mana pertandingan ini memberi peluang kepada generasi muda bagi melibatkan diri dalam pertandingan seperti debat dan pengucapan awam berkaitan isu-isu nuklear. Selain itu, para pelajar mampu menimba pengalaman yang baru dalam mengendalikan program yang bertaraf antarabangsa serta mampu meningkatkan kemahiran insaniah yang ada pada pelajar. Pertandingan ini telah disertai oleh pelajar-pelajar dari enam universiti awam iaitu UKM, Universiti Tenaga Nasional (UNITEN), Universiti Sains Islam Malaysia (USIM), Universiti Malaya (UM), Universiti Teknologi Malaysia (UTM) dan Universiti Universiti Putra Malaysia (UPM). Pertandingan besar ini telah dikendalikan dengan jayanya oleh pelajar Kelab Sains Nuklear (KESAN), FST UKM.



Sekitar program debat yang berlangsung sempena NYC2022.



Para pemenang NYC2022.



Pelajar KESAN, FST UKM yang bertugas sepanjang program iNuSTEC 2022.

Persidangan kali ini telah menobatkan tiga orang peserta dari UKM dan Nuklear Malaysia sebagai pemenang terbaik poster. Majlis perasmian penutup persidangan telah disempurnakan oleh Timbalan Dekan FST UKM, Prof. Ts. Dr. Wan Aida Wan Mustapha.



Majlis penutup iNuSTEC2022 disempurnakan oleh Timbalan Dekan FST, Prof Ts Dr Wan Aida Wan Mustapha.



Prof. Ts. Dr. Wan Aida Wan Mustapha bergambar bersama tetamu dan peserta selepas merasmikan majlis penutup iNuSTEC2022.

URANIUM-THORIUM FUEL MIXTURE ON REACTOR TRIGA PUSPATI (RTP) CORE KINETICS BY A SIMULATION APPROACH

Mohamed Ashraff Bin Dr. Mohamed Ali and Anas Bin Muhamad Pauzi

College Of Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor.

During the early stages of nuclear energy development in the year 1960's, Uranium and Thorium was being considered as possible fuel sources, but as researchers found that uranium and the by-products of the reaction had other uses, especially in the weapons industry, thorium study research was sidelined to allow the full research and development of uranium as an energy source for electricity generation and weapons manufacturing.

Recently, research on thorium as a nuclear fuel source is starting to regain popularity. Nevertheless, thorium has its drawbacks compared to uranium. The main problem researchers have found out about uranium is that Thorium fuel is fertile instead of fissile [1]. This means that it can only be used as a fuel in conjunction with a fissile material such as recycled plutonium. They also stated that, Thorium fuels can breed fissile uranium-233 (U-233) to be used in various kinds of nuclear reactors.

As for the nature of thorium, it is a naturally-occurring and slightly radioactive material. Thorium exists in nature in a single isotopic form – Thorium-232 (Th-232) – which decays very slowly. The decay chains of natural thorium and uranium give rise to minute traces of Thorium-228 (Th-228), Thorium-230 (Th-230) and Thorium-234 (Th-234), but the presence of these in mass terms is negligible. It decays eventually to lead-208 (Pb-208). In its pure state, Thorium is a silvery white metal that retains its lustre for several months. However, when it is contaminated with the oxide, thorium slowly tarnishes in air, becoming grey and eventually black. When heated in air, thorium metal ignites and burns brilliantly with a white light. Thorium dioxide (ThO₂). The most common source of thorium is the rare earth phosphate mineral, monazite, which contains an average of 6%-7%.

Since Thorium is not fissile, it cannot be used directly in a nuclear reactor to produce energy. However, because it is fertile, upon bombarding it with a neutron, the Thorium (Th-232) will transmute to uranium-233 (U-233) which is an excellent fissile fuel material. All thorium fuel concepts therefore require that Thorium-232 (Th-232) is first irradiated in a reactor to provide the necessary neutron dosing. Thorium fuels therefore need a fissile material as a 'driver' so that a chain reaction (and thus supply of surplus neutrons) can be maintained. The only fissile driver options are Uranium-233 (U-233), Uranium-235 (U-235) or Plutonium-239 (Pu-239) [2]. Unfortunately, none of the stated fuels are easily accessible.

Nevertheless, it is possible (but very difficult) to design thorium fuels that produce more uranium-233 (U-233) in thermal reactors than the fissile material they consume. (This is referred to as having a fissile conversion ratio of more than 1.0 and is also called breeding) [3]. Thermal breeding with thorium requires that the neutron economy in the reactor has to be very good. The possibility to breed fissile material in slow neutron systems is a unique feature for thorium-based fuels and is not possible with uranium fuels.

Energy is now considered as a major requirement for the continuous existence of humans on this planet. Energy is required to power basic amenities like healthcare, public safety, local businesses, small to large scale factories and many other, considered basic, human needs. Ever since the industrial revolution in the 18th century, the use of fossil fuelled power plants has also grown exponentially in order to meet the requirements of energy. At that time, it seems like fossil fuels was the ideal energy source. As the world population is continuously growing exponentially, so does the requirement of energy. As of 2007, the world consumption fossil fuels is at 11.1 billion tonnes [4] and as the days go by when the energy requirement

increases, fossil fuels are receding at an alarming rate.

Nevertheless, the supply of fossil fuel is said to last for another 100 over years. Even then, that does not mean that human should sit back and relax until the supply of fossil fuels dry out. Instead, alternative fuel sources should be researched and applied and take the place of fossil fuels. Nowadays, green energy and alternative fuel is becoming more popular. Ranging from small scale renewable energy like personal sized solar panel and wind turbines to power up a medium sized household and all the way to large scale green energy projects such as hydroelectric turbines, solar [5]. and wind farms [6] dedicated to power up small cities are being researched and some are currently being applied at a considerably large scale such as the Thorium Molten Salt Reactor [7], in the light water reactor [8]. and used in a pressurised water reactor [9].

As nuclear energy is gaining popularity, so is its demand for nuclear fuel, specifically Uranium-235 (U-235) and Uranium U-238 (U-238). Even though uranium is the most popular element used to obtain the required energy, there is still an alternative to the alternative, which is the use of Thorium-232 (Th-232) as a fuel source.

The reasons to opt for Thorium fuel cycle [10]. over other radioactive fuel cycles are due to the following reasons: [11]

The presence of Thorium – fuelled ADS[1].	Minimizing radio toxicity of nuclear waste. Uranium fuel required 30 000 years cooling time compared to Thorium which is 30 times less than that.
Abundant in nature and easy to mine for.	Thorium is widely distributed (average concentration of 10 ppm) in earth’s crust. Compared to uranium, thorium is more abundant by 3~4 times. Mining of thorium from monazite is simpler compared to mining for uranium from its ore.
Thorium-232 has better nuclear characteristics compare to uranium-235	Thorium-232 is more ‘fertile’ than U-238 in thermal reactors because of Th-232 has a higher thermal neutron absorption rate which is trice as more compared to Uranium-235. (7.4 barns as compared to 2.7 barns). This makes the conversion of Th-232 to U-233 more efficient than U-238 to Pu-239 in the thermal neutron spectrum.
More chemically stable and stable radiation resistance.	Thorium dioxide is chemically more stable and has higher radiation resistance than uranium dioxide. The fission product release rate for Thorium dioxide (ThO ₂)–based fuels are one order of magnitude lower than that of Uranium Dioxide.
Excellent past performance of Thorium dioxide (ThO ₂), (Th,U)O ₂ , ThC ₂ and (Th,U)C ₂ fuels in HTGRs.	The use of thorium-based elements used in the nuclear reactor core had demonstrated excellent performance in the past in the high temperature gas cooled reactors (HTGR) in several countries such as Germany, USA and the UK.
Non-proliferative nature of the fuel cycle [12].	Because of the nature of Thorium and its by-product, it is not suitable to be used as a nuclear war head. Therefore, the chances of it being misused and breaking Malaysia’s non-proliferation treaty is very small.
Less problematic in handling the trans-uranium (TRU) waste.	There are much less plutonium and Minor Actinides (MA: Np, Am and Cm) produced as compared to the Uranium-238 fuel cycle. Minimizing the toxicity problems. Minimizing the decay heat problems.

carried out by using the MCNPX2.6 software. Some of the research conducted was to study the behaviour of the fuels in the nuclear reactor, Reactor TRIGA-Puspati. For this study, a light water moderator was used because during its years of commercial operation, it has proven itself to be a successful nuclear based reactor in the energy generation sector. However, compared to light water, heavy water has a moderating coefficient which is 80 times smaller. The uses of water acts both as a moderator and a coolant to the reactor. Also, graphite and beryllium is commonly used as the reflector [2], even though there are other alternative moderators. Compared to other materials, Beryllium Oxide (BeO) will act as a much better reflector [3].

By using the MCNP2X Monte Carlo code that was developed by the Los Alamos National Library, the simulation, calculation along with the analysis was conducted. The code is a general-purpose Monte Carlo Code [9], which will facilitate independent or coupled neutron, photon and electron transport calculation [13] s. The code will treat it as an arbitrary three-dimensional configuration of material and geometric cell. At the same time, the software will provide a versatile description of the source, the variance reduction methods, a flexible tally structure, and a vase collection of cross-section data in never-ending energy representation. Also, the software will cover the energy that ranges from 1×10^5 all the way to 20MeV.

The neutron-induced cross-sections at 293K was applied using the ENDF/B-VI nuclear data library. In this research, the researchers considered the following two processes;(1) Inelastic scattering occurs with the cross section σ_{in} and a coupled energy-angle representation which was derived from ENDF/B S(α , β) scattering law. (2) elastic scattering with no change in the outgoing neutron energy for solids with cross-section σ_{el} . and an angular treatment derived from lattice parameters.

The simulation was conducted with the thermal region being defined in an energy range of $10^{-5} < E < 0.025$ eV and the core materials was selected based on table 1 when a KCODE card with 5000 neutrons and 250 active cycles along with 50 inactive cycles.

The calculations conducted was specifically targeting at obtaining a suitable neutron flux and having a reduced enrichment value within the compact core. In order to find the optimal geometry setting, an initial set-up was used and the geometry was gradually optimized until the set requirements is achieved. For this research, the design was considered to be at a diameter and height of 120 cm and 140cm respectively. The core was configured to have 19 fuel elements with 19 assemblies of 100cm height in each assembly. A 5cm thick Beryllium Oxide (BeO) reflector was considered around the core. [10]. The fuel elements, a (Th,U) O_2 fuel element, with the diameter of 2cm and 2.2% U-235 enrichment was used. Also, acting as the moderator was heavy water. There were 0.5cm, 1 cm and 2 cm gaps in between the assemblies and fuel pins respectively and a 0.2cm stainless steel covering the Be) reflector.

To reduce the neutron leakage, a method used was to select a reflector which has a proper composition and thickness. If the neutrons diffuses far enough into the reflector, there is a high chance that some will diffuse back into the core. Therefore, the reflector was optimized by varying the Beryllium Oxide (BeO) thickness from 5 cm up to 30 cm.

Six silver alloy control rod was used [14], in order to avoid criticality accidents,. The reactivity was defined using the following formula:

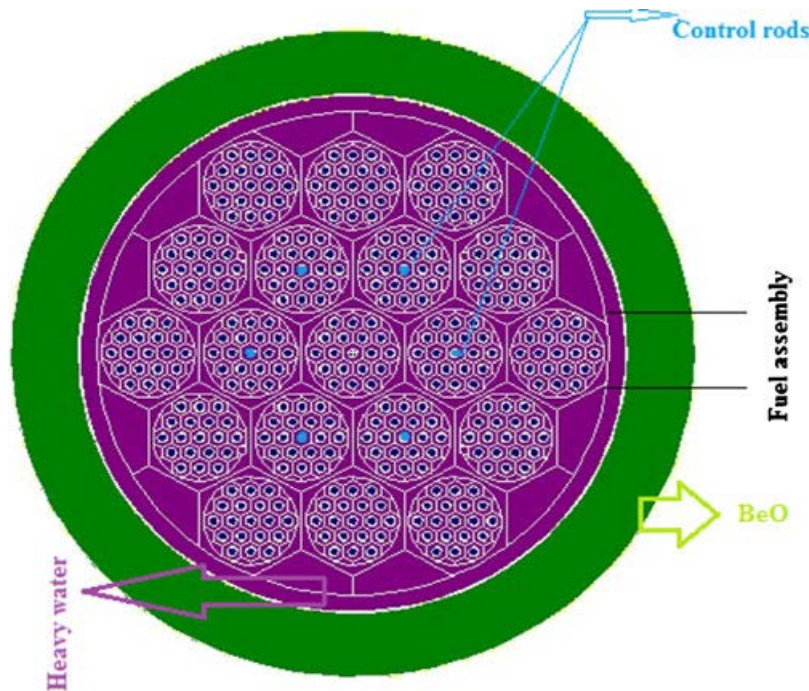
$$\rho = \frac{K_{eff}-1}{K_{eff}}$$

The effective delayed neutron fraction was the unit used to when the reactivity was measured in fractions. A unit of ρ/β_{eff} is called a dollar [15], where β_{eff} is the effective delayed neutron fraction

Material	Composition (wt%)	Thickness (cm)	Density (g/cm ³)
Fuel	(U,Th)O 235U:2.2, 232Th: balance	2.00	10.00
Cladding	Zircaloy-4 Sn:1.4, Fe:0.23, Cr:0.1, and Zr SS304	0.04	6.50
Cover plate	Fe:69.5, Cr:19.0, Ni:9.5, Mn:2.0 side	0.2 variable	7.92 3.00
Reflector	Be:36, O:64 Top & Bottom	2.00	2.00
Control rods	Cd:4.9, Ag:80.5, In:14.6	2.08	9.32

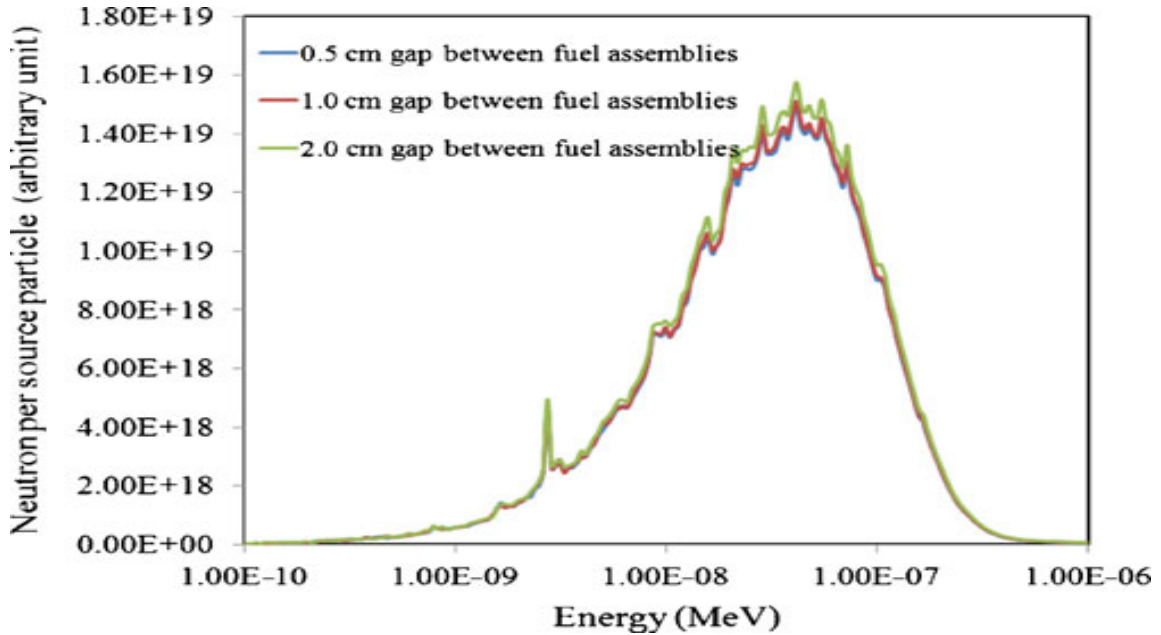
Core Material Composition

In the simulations that was carried out, the Neutronic parameters of the fuel setup; hexagonal, 10-assembly core, Thorium-235 and U-235 mixture, 2.2% fuel enrichment, enrichment was considered. A k_{eff} value of 1.00026 was obtained for the configuration of 19 fuel elements in each of its 19 assemblies, where each fuel was interspaced of 0.5cm and was arranged in a hexagonal shape in a core of surrounded by a 274,750 cm³ heavy water moderator and is 120 cm in diameter. By increasing the gap between the assemblies to 1 and 2 cm, a decrease of k_{eff} to 0.99680 and 0.97491 had occurred, respectively, while still using a 5 cm Beryllium Oxide (BeO) reflector.



Critical core which is 15 cm thick of Beryllium Oxide (BeO with configuration consisting of 19- assemblies.

The calculations showed relative discrepancies when using the 2 cm fuel assembly gap in comparison with 1 cm gap as shown in the following figure. Thus, 0.5 cm gap seems to be most suitable.

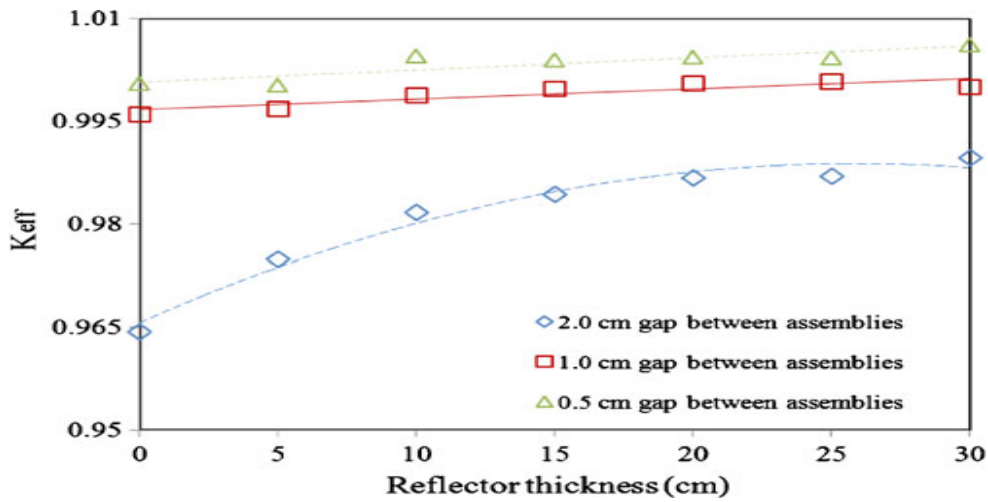


Neutron spectra Comparison of core with various gaps between fuel elements.

The uses of different Beryllium Oxide (BeO) thickness also cause some fluctuations in the k_{eff} value as tabulated in following table.

<i>Effect of different thickness Beryllium Oxide (BeO) on k_{eff}</i>							
BeO thickness (cm)	0	5	10	15	20	25	30
2 cm gap between fuel assemblies							
K_{eff}	0.96432	0.97491	0.98171	0.98435	0.98676	0.98701	0.98971
SD (pcm)	53	49	51	48	47	42	45
1 cm gap between fuel assemblies							
K_{eff}	0.99607	0.99680	0.99883	0.99977	1.00052	1.00079	0.99995
SD (pcm)	49	47	50	48	47	50	45
0.5 cm gap between fuel assemblies							
K_{eff}	1.00052	1.00026	1.00454	1.00396	1.00437	1.00428	1.00618
SD (pcm)	49	49	49	47	48	51	48

The k_{eff} value were more stable around the 2cm gap between assemblies compared to 1cm and 0.5cm. When the gap was 0.5 cm, k_{eff} fluctuations were less compared to the rest. As a matter of fact, additional volume of water can itself act as a reflector and reduce the presence of thermal neutrons in the Beryllium Oxide (BeO) reflector. However, by increasing the thickness of the reflector will make the reflector act like a shield for neutrons and will decrease the scattering of neutrons which is aimed to the centre of the core. Thus, the simulation was conducted to observe the most suitable reflector thickness.



Comparison of reflector neutron spectra with different reflector thicknesses.

By using the Monte Carlo MCNP software, a 3-dimensional simulation developed a versatile and accurate full model of the TRIGA core and its fuel elements. The script was compiled in order to run a simulation in the MCNP software to obtain the neutron flux distribution.

Using the MCNP software, neutron flux distribution had predicted that the thermal flux values seem to be higher than the experimentally determined values. This difference in values was discussed to be due to error in physical model or the temperature effect, which was neglected in MCNP calculation. Nevertheless, the magnitude of this effect is believed to be neglect able. In order to calculate the neutron flux distribution, the following equation, was used.

$$\Phi_{total} = \Phi F_4 \times (Power\ Level \times u) \div (Q_{value} \times k_{eff})$$

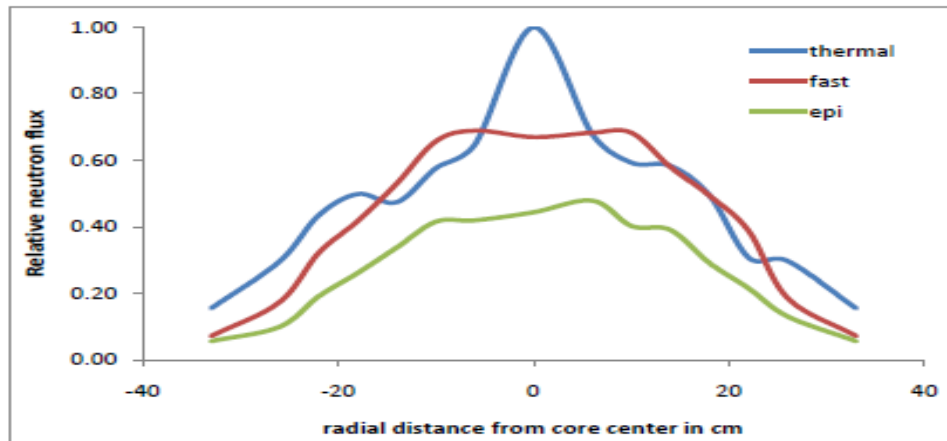
where; Φ is neutron flux

u is average neutron emitted per fission

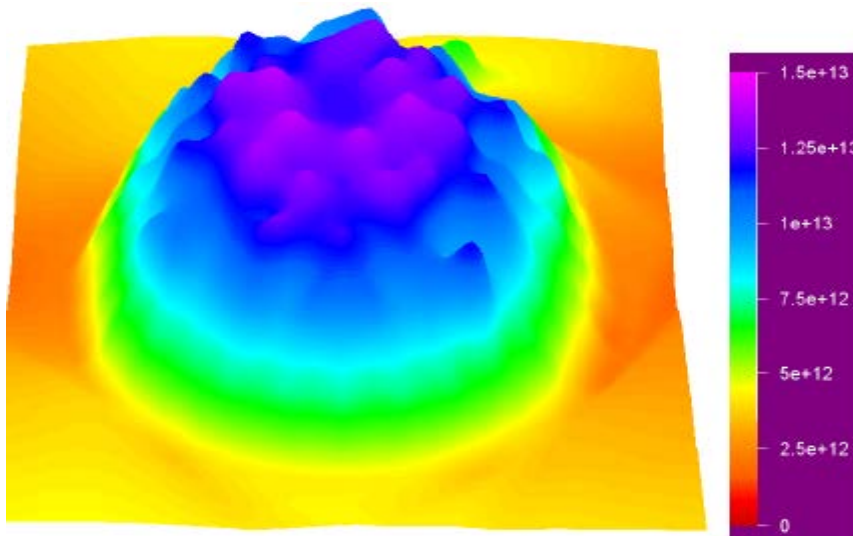
Q is recoverable energy per fission

The thermal neutron energy considered to be all energy below 0.5 eV which is the energy cut-off for Cadmium that was used in neutron flux measurement. The k_{eff} predicted by MCNP was 1.12728 ± 0.00071 which is higher than the measured one which is 1.091036, this is expected since the MCNP does not taking into account the fuel burnup.

The neutron flux distribution inside the reactor core was determined to be dependent on the different types of elements in it. The maximum neutron flux will be distributed towards core centre. Actually, it was found that the maximum thermal neutron flux was at the Central Thimble location. Since this area has been filled with a moderator, which is water, the fast neutrons were thermalized. But at the edge of the core, the thermal flux was relatively higher than the fast flux because of the graphite reflector effect.



Radial Flux Distribution

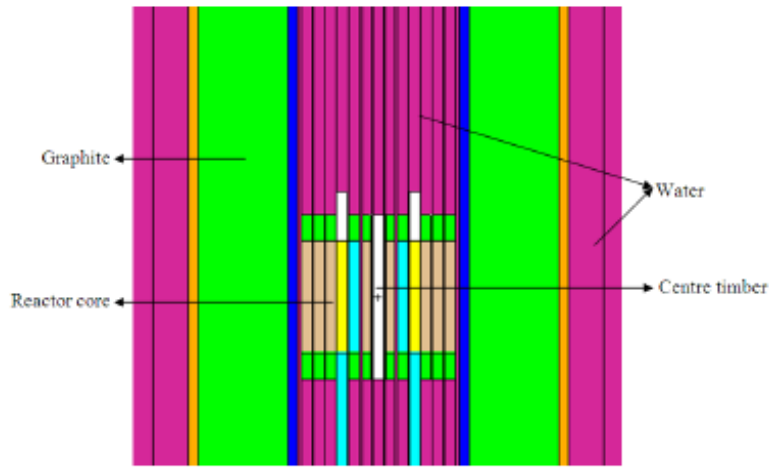


Fast Neutron flux distribution

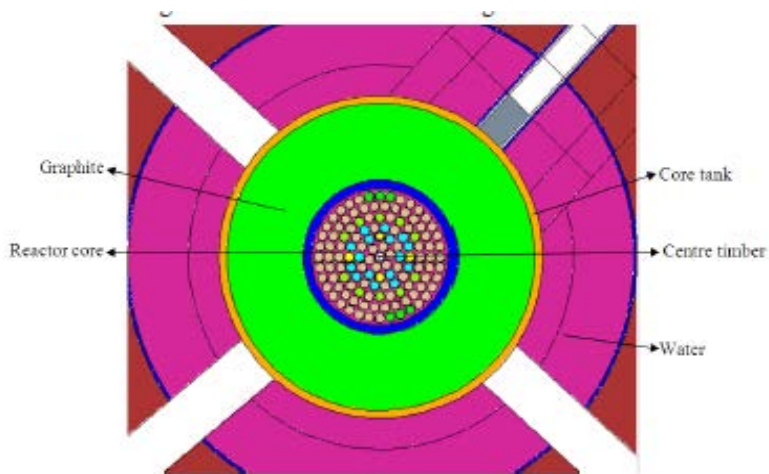
Based on the experiment conducted, it was said that the Radial and axial neutron flux distribution was much more depends on the fuel loading pattern and location in the core. Also, the result obtained reinforces the reliability of the MCNP software for the design verification and reactor core parameters calculation.

The Monte Carlo MCNP software can be used to calculate the criticality of the Triga Mark II Pool Type Reactor. This research paper provides the required information regarding using the Monte Carlo simulation to simulate the capabilities of that reactor in fulfilling its safety function.

Using the MCNP5 software [14], a complete model of RTP which was constructed. The constructed core was based on the 12th core configuration which is made of of 114 correctly positioned fuel rods, 10 of flux holes, 6 dummy fuel rods, 3 control rods of fuel-follower type are used i.e. regulating, (R), Shim (C), and safety (S), 1 air-follower control rod (transient rod), reactor tank, graphite reflector and centre timber. The fuel elements constructed was represented as cylinders with the respected dimensions and materials, at the exact locations. The core centre was assumed as the origin with the coordinates; (0, 0, 0) in the x-y plane. In the 12th configuration, 88 fuel elements of 8.5wt%, 16 fuel elements of 12wt% and 10 fuel elements of 20wt% was used.



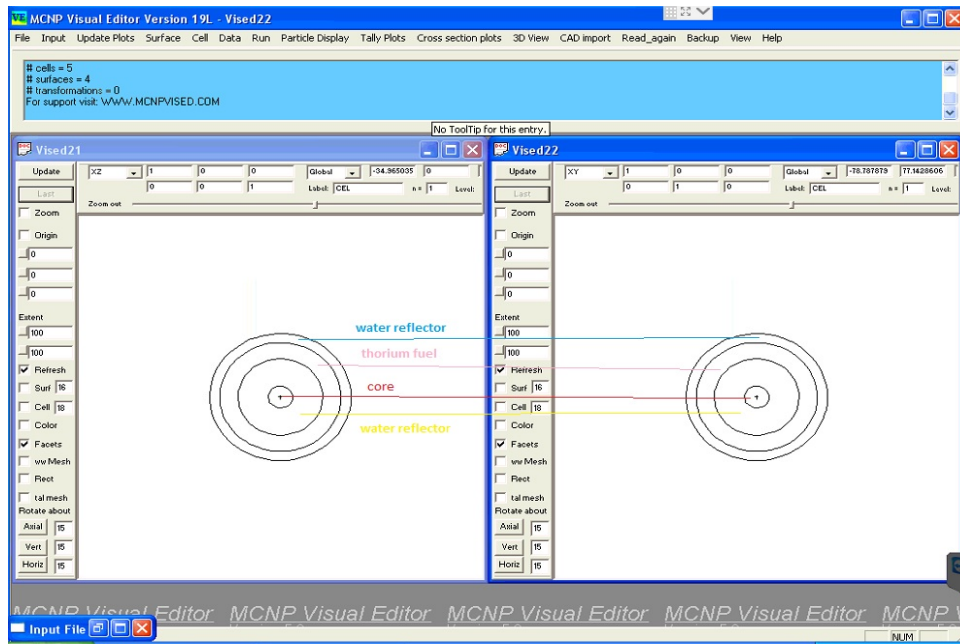
Axial Model for the RTP configuration in MCNP5



Radial Model for the RTP configuration in MCNP5

Based on the conducted simulation, it can be concluded that the physical parameters such as the k_{eff} , flux distribution, dose and several other parameters was obtained and was tabulated in following table.

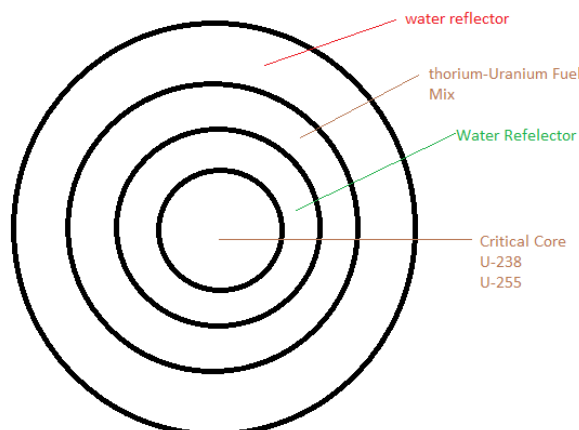
<i>Comparison of the MCNP5 calculation and SRAC calculation</i>			
Effective multiplication factor (Control rods fully withdrawn) by MCNP5 code	1.10773 ± 0.00083	Effective multiplication factor (Control rods fully withdrawn) by SRAC code	1.0876
Effective multiplication factor (Control rods fully inserted) by MCNP5 code	0.98370 ± 0.00054	Effective multiplication factor (Control rods fully inserted) by SRAC code	0.8435



Reactor Core Design MCNP Visual Editor. Front view (left), Top View (Right)

It was concluded that by using the MCNP5, it was an advantage compared to using the deterministic methods. This is because the MCNP5 software is powerful code for the criticality calculation which may be hard to be achieved by deterministic calculations.

For the first core design, the first core is known as the critical core. In this first core, it will be the source Uranium-238 (U-238) and Uranium-235 (U-235) particles. The 2nd sphere will be a water reflector. The water used here will be heavy Water. The third Sphere is filled with a Thorium-232 (Th-232)-Uranium-232 fuel mixture. The fourth sphere is filled with the Heavy Water which acts as the reflector, similar to the second sphere. In both the second and fourth sphere, the heavy water acts as the reflector to focus the neutrons in the thorium-Uranium region.



Simplified view of the Reactor core

Core design has been constructed using the MCNP4C Student Version and the MCNP Visual Editor Version 19L, the construction of the fuel card can be constructed.

The construction of the reactor core which was discussed in the previous sub-topic (3.3.8. Constructing the

reactor core). The third sphere is where the thorium fuel is assembled and the fourth sphere is where the uranium-233 element is located. For an ideal state, the core was designed such that the entire third sphere was to be the location of all the thorium fuel. For this design, the difference between the third and fourth sphere will always be 9cm in radius. This means the difference in the diameters was 9cm. The third and fourth sphere will change according to the sphere formula (equation below).

$$A = \left(\frac{\pi}{4} * 30cm^2\right) - \left(\frac{\pi}{4} * rcm^2\right)$$

where A= Effective area of thorium

R= radius of the third (thorium) sphere.

The dimensions of the third and fourth sphere is tabulated below:

Percentage of thorium to effective area of thorium

Thorium (%)	Percentage	Radius (cm)	Effective area (thorium) [cm ²]
100		21.00	360.498
90		21.90	330.174
80		22.80	298.577
70		23.70	265.708
60		24.60	231.567
50		25.50	196.153
40		26.40	159.467
30		27.30	121.509
20		28.20	82.278
10		29.10	41.775

From the table above, it can be seen that as the radius of the third sphere, thorium filled sphere, decreases with respect to the percentage of thorium in the sphere itself, and the effective area also decreases. Inversely, as the effective area of the thorium decreases, the effective area of the uranium will gradually increase.

```

Sample coding (100% Thorium dioxide).
Thorium criticality
c ===== cells =====
10  1  4.84101E-02  -1  imp:n=1  $ critical compound
20  2  1.00343E-01  1 -2  imp:n=1  $ water reflector
30  3  0.878809    2 -3  imp:n=1  $ Thorium
40  4  1.00343E-01  3 -4  imp:n=1  $ water reflector
99  0  0  4  imp:n=0  $ outside world

c ===== surfaces =====
1  SPH_0 0 0 0 6
2  SPH_0 0 0 0 21
3  SPH_0 0 0 0 30
4  sph_0 0 0 0 35
    
```

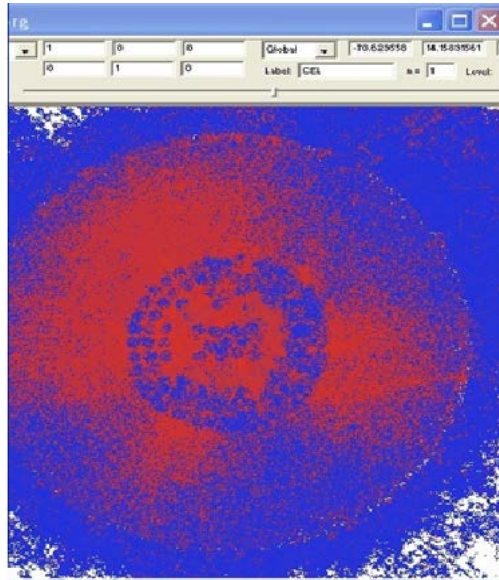
Example of fuel and reactor core script.

In order to manipulate the thorium-uranium content in the third and fourth sphere respectively, the basic script needs to be manipulated to meet the size requirements based on the values in previous table. The sphere 2 and sphere 3 is 21 cm and 30 cm respectively. The absence of a fifth sphere is because in this situation of 100% thorium filled sphere, the 3rd sphere is 9cm (in radius) filled with thorium. This translates to the core having 360.498 cm² of thorium. As the thorium percentage decreases, so does the effective area of thorium. The effective area ranges from 360.498cm² at 100% thorium-0% Uranium and 41.775cm² at 10% thorium-90% Uranium.

In order to determine the most suitable nuclear reactor design and thorium-uranium fuel configuration, a study on the particle distribution needs to be conducted first. In order to conduct this study via simulation, the MCNP4C and MCNP Visual Editor Version 19L needs to be done.

The reason the particle distribution was done prior to real simulation was to ensure that there would be enough energy throughout the configured reactor core designed during the fission process [2]. The particle display simulation works in a where will track then display the number of neutron collisions, along with the neutron source that occurred in the reactor. The tracking of the neutrons was to find out how many neutrons would collide with the thorium-uranium mixture.

High amounts of collisions will result in a high amount of energy at that area due to the high concentration of neutrons colliding at that area. Nevertheless, since the MCNP software does not track the amount of neutrons absorbed nor does it detect the amount of neutrons released, the particle display cannot be used as tool to evaluate the criticality of the of the nuclear reactor. Therefore, the sustainability of a nuclear chain reaction cannot be determined just by conducting the particle display simulation.

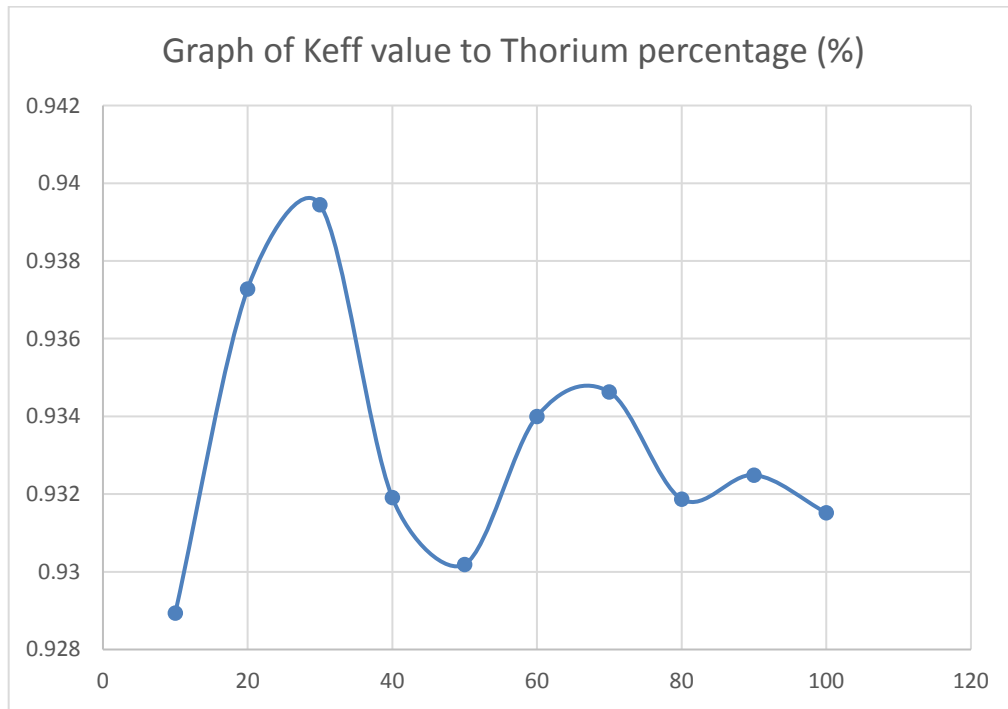


Particle display of designed

Based on the studied design, it can be seen that most of the neutrons available for bombardment with the thorium-uranium fuel is located just outside the centre of the reactor core (red particles) whereas it is seen less in the outer region (blue region). This is because due to the water reflectors on sphere two and sphere five are reflecting the neutrons back into that said area. This makes it a suitable location to place the thorium-uranium fuel mixture.

From the experiment conducted using the MCNP4C Student Version and MCNP Visual Editor Version 19L software, the k_{eff} results were obtained with respect to the difference in the thorium content in the reactor core. The results of the simulation have been tabulated in the following table.

<i>Percentage of thorium to effective area of thorium</i>		
Thorium Percentage (%)	Thorium-232 weightage	k_{eff}
100	0.8788090	0.93152
90	0.7909281	0.93249
80	0.7030472	0.93187
70	0.6151663	0.93463
60	0.5272854	0.93400
50	0.4394045	0.93019
40	0.3515236	0.93191
30	0.2636427	0.93945
20	0.1757618	0.93728
10	0.0878809	0.92894



k_{eff} values to Thorium percentages (%)

Based on the Graph of k_{eff} value to Thorium percentage (%), it is seen that as the percentage of the thorium increases, the k_{eff} value gradually fluctuates in a sinusoidal manner between 0.94 to 0.93 until it approaches the k_{eff} value of 0.932.

The simulation using the MCNP4C Student Version and MCNP Visual Editor Version 19L software, conducted also was used to obtain the data of Standard Deviation related to the k_{eff} value. The results of the simulation have been tabulated in the following table.

<i>k_{eff} values to Standard Deviation</i>		
Thorium Percentage	Thorium-232 weightage	Standard Deviation
100	0.878809	0.00305
90	0.7909281	0.00282
80	0.7030472	0.00252
70	0.6151663	0.003313
60	0.5272854	0.00331
50	0.4394045	0.00288
40	0.3515236	0.0033
30	0.2636427	0.00259
20	0.1757618	0.00312
10	0.0878809	0.00288

Based on the Graph of standard deviation to k_{eff} value, it is seen that the values of Standard deviation

fluctuate between the values of 0.0035 to 0.0025 in a very inconsistent manner. For all k_{eff} values, it is seen that the standard deviation did not exceed more than 0.0035. This means the variation of all k_{eff} values obtained from the 60 cycles simulated did not vary much from each other [15].

As an overall conclusion, it can be said the neutronic behaviour of the neutrons of the thorium-uranium fuel acting in the designed nuclear reactor was not suitable. This is because a self-sustaining nuclear chain reaction could not be obtained. Even the most suitable configuration, a 30% thorium fuel configuration, could not meet the requirements for a self-sustaining nuclear chain reaction which is k_{eff} must equals to 1.

Therefore, in order to achieve a self-sustaining nuclear chain reaction, there are several procedure that can be done in order to design an appropriate configuration. One of it is to construct a more fissile nuclear fuel. Since the configured fuel produced a subcritical result, a more fissile nuclear element could be used and tested using the MCNP software since conducting a hands-on experiment could prove to be costly and too time consuming.

Another way to improve the configuration to become a more self-sustaining nuclear chain reaction, the design of the nuclear reactor needs to be improved. Even though the current nuclear reactor design is said to be the most ideal, it can further be improved. A better nuclear reflector may be used in order to reflect more neutrons back to the centre core. By doing so, this can boost up the k_{eff} values and in turn may allow a self-sustaining nuclear chain reaction to be obtained.

Thus, it can be concluded that, the thesis aim has been achieved. The neutronic simulation of the thorium-uranium fuel mixture has been observed. Unfortunately, the fuel configuration and the reactor design has been proven to be unsuitable for energy production use.

ACKNOWLEDGEMENT

I would like to take this opportunity to extend my deepest gratitude to my project supervisor, Mr. Anas bin Muhamad Pauzi. His knowledge and experience proved to be vital in the completion of my research. Without his help and guidance, my research would have not been possible to complete. I would like to take this opportunity to thank Prof. Madya Dr. Abdul Aziz bin Mohamed. His guidance and expert advice provided a pivotal role on the completion of this thesis. Without his guidance, this final year project would have not been possible. Other than that, I would like to thank the Malaysia Nuclear Agency for their guided help. Their expert advice regarding nuclear energy and nuclear particle behaviour provided me the accurate knowledge required for the completion of this research. Moreover, I would like to thank all those who had provided the extra morale support that helped in the completion of the research and thesis.

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MATERIALS DATA

Table of Properties of Heavy Water

353 Water, Heavy						
Formula =		D2O		Molecular weight (g/mole) =		20.02760356
Density (g/cm3) =		1.105340		Total atom density (atoms/b-cm) =		9.971E-02
The above density is estimated to be accurate to 4 significant digits. Uncertainties are not addressed.						
The following data was calculated from the input formula.						
<u>Element</u>	<u>Neutron ZA</u>	<u>Photon ZA</u>	<u>Weight Fraction</u>	<u>Atom Fraction</u>	<u>Atom Density</u>	
H-2	1002	1000	0.201133	0.666667	0.066473	
O	8016	8000	0.798867	0.333333	0.033237	
Total			1.000000	1.000000	0.099710	
<u>MCNP Form</u>	<u>Weight Fractions</u>		<u>Atom Fractions</u>		<u>Atom Densities</u>	
Neutrons	1002	-0.201133	1002	0.666667	1002	0.066473
	8016	-0.798867	8016	0.333333	8016	0.033237
Photons	1000	-0.201133	1000	0.666667	1000	0.066473
	8000	-0.798867	8000	0.333333	8000	0.033237
CEPXS Form:	material	H-2	0.201133			
		O	0.798867			
	matname	Water, Heavy				
	density	1.105340				
<i>Comments and References</i>						
The National Physical Laboratory, which is the national measurement standards laboratory for the United Kingdom, lists the density for D2O for T=0° to 100°C (http://www.kayelaby.npl.co.uk/general_physics/2_2/2_2_1.html). At T=20°C, the density = 1.10534 g/cm3 at 101.325 kPa (1.0 atm) from measurements in 1949, 1951, and 1963. Density = 1.1054 g/cm3 is from Petrie et al. (2000). Density = 1.1056 g/cm3 at STP (20°C) is listed at http://en.wikipedia.org/wiki/Heavy_water . Also call deuterium oxide.						

Table of Properties of Natural Uranium

347 Uranium, Natural (NU)						
Formula =		-		Molecular weight (g/mole) =		-
Density (g/cm ³) =		18.950000		Total atom density (atoms/b-cm) =		4.794E-02
The above density is estimated to be accurate to 3 significant digits. Uncertainties are not addressed.						
The following data were calculated from the input weight fractions.						
<u>Element</u>	<u>Neutron ZA</u>	<u>Photon ZA</u>	<u>Weight Fraction</u>	<u>Atom Fraction</u>	<u>Atom Density</u>	
U-234	92234	92000	0.000057	0.000058	0.000003	
U-235	92235	92000	0.007204	0.007295	0.000350	
U-238	92238	92000	0.992739	0.992647	0.047591	
Total			1.000000	1.000000	0.047944	
MCNP Form	Weight Fractions		Atom Fractions		Atom Densities	
Neutrons	92234	-0.000057	92234	0.000058	92234	0.000003
	92235	-0.007204	92235	0.007295	92235	0.000350
	92238	-0.992739	92238	0.992647	92238	0.047591
Photons	92000	-0.000057	92000	0.000058	92000	0.000003
	92000	-0.007204	92000	0.007295	92000	0.000350
	92000	-0.992739	92000	0.992647	92000	0.047591
CEPXS Form:	material	U-234	0.000057			
		U-235	0.007204			
		U-238	0.992739			
	matname	Uranium, Natural (NU)				
	density	18.950000				
<i>Comments and References</i>						
See pg 286 of Shleien (1992).						
Density for natural uranium = 18.95 g/cm ³ , http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=092 (NIST 1998).						

Table of Properties of Thorium

310 Thorium						
Formula =		Th		Molecular weight (g/mole) =		232.0381
Density (g/cm ³) =		11.720000		Total atom density (atoms/b-cm) =		3.042E-02
The above density is estimated to be accurate to 4 significant digits. Uncertainties are not addressed.						
The following data was calculated from the input formula.						
<u>Element</u>	<u>Neutron ZA</u>	<u>Photon ZA</u>	<u>Weight Fraction</u>	<u>Atom Fraction</u>	<u>Atom Density</u>	
Th	90232	90000	1.000000	1.000000	0.030417	
Total			1.000000	1.000000	0.030417	
MCNP Form	Weight Fractions		Atom Fractions		Atom Densities	
Neutrons	90232	-1.000000	90232	1.000000	90232	0.030417
Photons	90000	-1.000000	90000	1.000000	90000	0.030417
CEPXS Form:	material	Th	1.000000			
	matname	Thorium				
	density	11.720000				
Comments and References						
Density from http://physics.nist.gov/cgi-bin/Star/compos.pl?matno=090 (NIST 1998).						