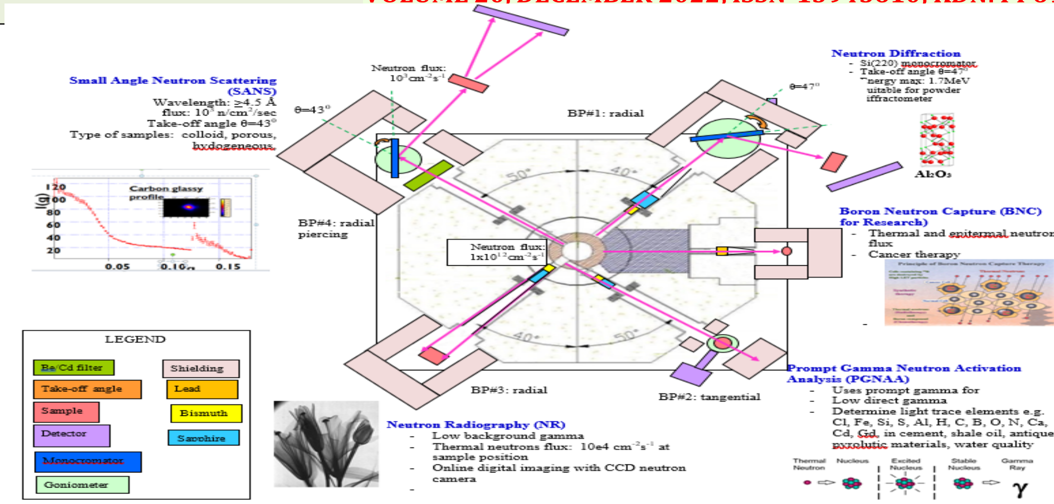
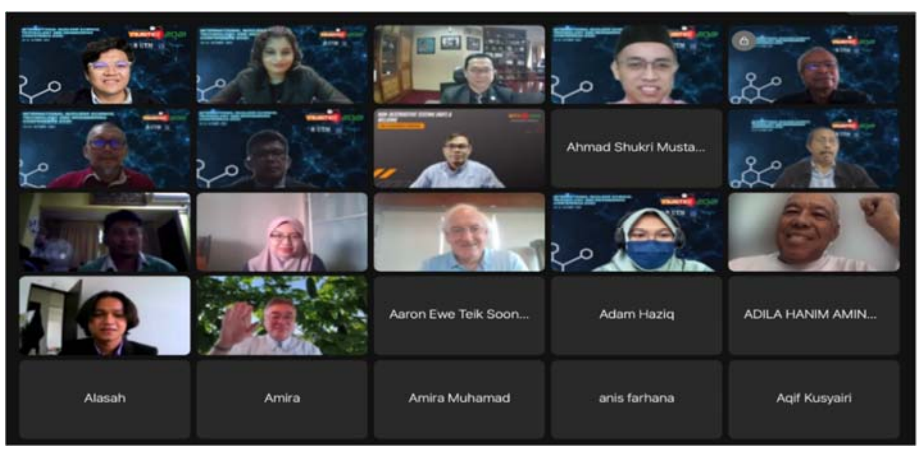
BULETIN
NUKLEAR MALAYSIA

NUCLEAR BULLETIN OF MALAYSIA

RM5.00

VOLUME 26, DECEMBER 2022, ISSN 13945616, KDN: PP 8942/1/2004





The National Nuclear Science, Technology, Engineering and Commerce Communication Media

Published by The Malaysian Nuclear Society (MNS)

BULETIN NUKLEAR MALAYSIA

Volume 20, December 2022

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Published by

Malaysian Nuclear Society (MNS)

c/o Malaysian Nuclear Agency (Nuclear Malaysia), Bangi, 43000 KAJANG Selangor D.E. Malaysia

Tel: 603-89250510; Fax : 603-89202968

Website: http://www.nuklearmalaysia.org

EDITORIAL

After working hard by the editorial members, the issue of Vol. 20 of BNM is finally published.The editorial would like to apologies 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 sprit 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. Differentauthors 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 scenarioand trend of world energy demand, food and water security, environmental concerned, it is hopethat articles and news related to nuclear and nuclear related issue, in particular could be a “hot” topic of discussion.

Chief Editor

Bulletin Nuclear Malaysia, December 2022

NEUTRON BEAM FACILITIES AT RTP

Faridah Mohamad Idris, Julie Andrianny Murshidi, Azraf Azman, Khairah Yazid, Abdul Aziz Mohamed, Mohd Rizal Mamat, Norfarizan Mohd Said, Hafizal Yazid, Roslan Yahya, Julia Abdul Karim
Reactor Interest Group (RIG), Malaysian Nuclear Agency,
PUSPATI, Bangi, 43000 Kajang, Selangor, Malaysia

Introduction

TRIGA PUSPATI (RTP) is a 1MW research reactor located in Malaysian Nuclear Agency, Bangi, Selangor, Malaysia. RTP was commissioned in June 1982. In 1985, Neutron Radiography (NR) facility was commissioned at beamport#3 of RTP. This facility was refurbished in 2017 with new collimator and shielding bunker. Small Angle Neutron Scattering (SANS) facility was installed in 1995 and experienced upgrading through in-house design systems throughout the years. New facilities such as Neutron Diffraction (ND), Boron Neutron Capture (BNC) research and Prompt Gamma Neutron Activation Analysis (PGNAA) facility are now under development at RTP. This paper discusses the characteristics of these neutron beam facilities which were used in their designs.

Collimator And Shielding Design

To increase the research and development (R&D) works using neutron beam from RTP, the beam ports and thermal column of RTP needs to fitted with suitable collimator and shielding design. These would ensure that the neutron beam could be used for specific research works. Each of the neutron beam facilities in RTP was developed using the neutron spectra available. With four beamports and one thermal column, the quality of these neutron beams was design with followings:

(i) Collimator with gamma and fast neutron filters used

(ii) Neutron energy exiting the beamport

(iii) Shielding design for the neutron beam instrument

The design of item (i) to (iii) as shown in Figure 2 were selected to give each of the beamport the quality needed for its targeted purpose such as:

- NR,
- SANS, ND,
- BNC research and
- PGNAA

The designs were developed and fabricated as a result of IAEA TC MAL 1012 (Capacity Building in Basic Neutron Science and Engineering for Education, Training and Research Using TRIGA Mark II Research Reactor), research collaboration with regional research institutions and local universities using the platform Reactor Interest Group (RIG), a loosely form parties interested in reactor utilization initiated by Nuklear Malaysia in 2001.

How Neutron Scattering Works

In neutron scattering, **Bragg's Law** has been widely used to calculate the neutron scattering angle off a lattice, Figure 1 shows a typical neutron beam (double arrows) that hits a material surface at an incident angle θ and scattered off at from this surface. These scattered neutrons could be collected and analysed by a detector such as position sensitive detector (PSD).

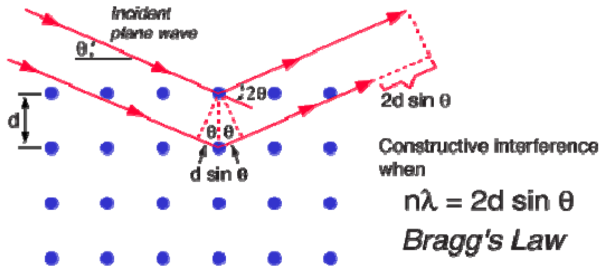

Figure 1. Bragg's Law that calculates the neutron scattering angle off a lattice. (Source: http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/bragg.html)

As neutron has a particle duality, i.e. it can also have a wavelike property, neutron propagating the target the material could be described by a wavelength λ. The neutrons can thus experience interference, whereby neutrons with the same wavelength could form maximum intensity. In Figure 1, wavelength of the neutron could be written in terms lattice spacing d, as:

$$n\,\lambda = d \sin \theta \tag{1}$$

where n is an integer. Thus, the neutron scattering using Bragg equation as above has been widely used to design neutron scattering facilities for specific analysis such as small angle neutron scattering, neutron diffraction, neutron intereferormeter etc.

Figure 2 shows the layout of the neutron beam facilities at RTP. Neutron radiography facility at beamport # 3 is used for neutron tomography imaging, while small angle neutron scattering at beamport #4 is used for nanomaterial characterization. At beamport #1, collimator and shielding has been installed for neutron diffraction. At the thermal column, mobile shieldings and stopper are used for experiments in boron neutron capture research, at beamport #2, prompt gamma neutron activation facility is being planned.

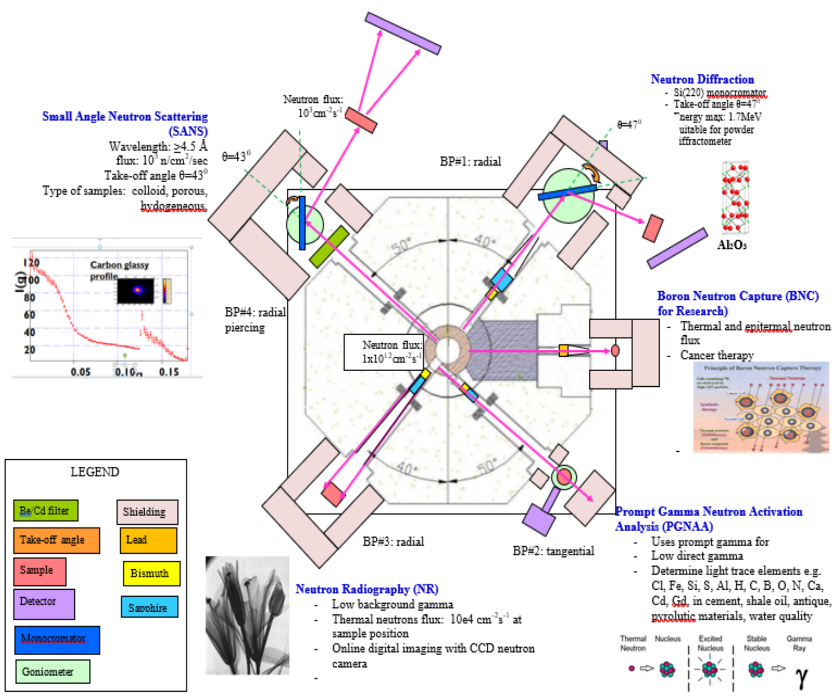

Figure 2. Neutron beam facilities layout at RTP.

PRELIMINARY STUDY ON NUCLEAR BATTERIES FROM NUCLEAR WASTES

Iman Syahmi Jasni[1] and Julia Abdul Karim[2]
[1]MARA Junior Science College Serting, Negeri Sembilan, Malaysia
[2] Malaysian Nuclear Agency, PUSPATI, Bangi, 43000 Kajang, Selangor, Malaysia

1. Introduction

Batteries promise an era of portability as it powers devices and vehicles via electrochemical technology applying Lithium ion (Li-ion). However, its design depends mostly on the chemical properties of its electrode and electrolyte to aid the ions flow. This design faces two fatal flaws; the limited amount of material can be used to manufacture the battery and the electrolyte of most batteries being sensitive to temperature. These flaws can be overcome by tuning to nuclear electric technology such as Radioisotope Thermoelectric Generator (RTG), Stirling Radioisotope Generator (SRG) and Betavoltaics. These technologies operate under different physical processes. In this paper, betavoltaics technology is studied and emphasized on its potential and advantages over electrochemical technology.

An electrochemical cell relies on the electronegativity difference between two or more ions while a betavoltaic cell functions under the radioisotopes decay that releases beta particles (energy) to induce electrical current. This is the main advantage of betavoltaic cells as its power output is not affected by the cell pressure and temperature which makes it more versatile. This cell has an *active electrolyte* compared to electrochemical cells that has an *active electrode*. It is also known as a *non-contact electrolyte cell* because the radioisotopes do not necessarily required to contact with the electrodes to function.

The longevity of electrochemical and betavoltaic cell rely on the half-life of chemical reactions and half-life of radioactive decays respectively which has a relation to the *electromotive force* (emf) produced. The betavoltaic cell longevity could match or be orders of magnitude longer than electrochemical cell. Promethium-147 (Pm-147) having a half-life of 2.62 years which is similar to lithium cell. Longer half-lives are better however other factors must be considered such as electron energy and by-products of radioactive decay. A long half-life can be shown from the voltage measurement of the cell being relatively stable over long periods of time.

Betavoltaic cell is safer than electrochemical cell because it does not influence by chemical and thermal conditions. Therefore, runaway discharge/reaction will not occur inside the cell. This overcome the main problems facing by high energy density cells where they have the tendency to catch fire and being exploded when physically punctured or damage happened. Furthermore, beta radiation is easy to block and has low ionizing energy which makes it the “goldilocks” particle radiation source to make a nuclear battery. Betavoltaic cell offers the option of a portable and convenient energy dense source that has none of the shortcomings from chemical cells.

Nuclear waste are radioactive substances that is usually the by-product of various nuclear processes. The major source of nuclear wastes come from Industries namely nuclear medicine, nuclear research, vehicle production lines, bottling and canning and rare-earth mining. There are three types of nuclear waste, classified according to their radioactivity: Low-Level Waste (LLW), Intermediate-Level Waste (ILW) and High-Level Waste (HLW). LLW is not dangerous due to very low activity and it can be disposed easily in landfills meanwhile ILW which has higher activity than LLW but lower than HLW usually a fraction of its original activity. ILW requires some shielding when handling and long-term storage in a waste repository. Pm-147 is an example of ILW which usually used for measuring car components thickness.

Producing radioisotopes consume more time and energy. On the other hand, nuclear waste (spent nuclear fuels and decommissioned nuclear warheads) are recyclable. The remaining radioisotopes in the nuclear waste are economical enough to be recovered and reused to generate electricity. This approach is particularly well-suited to low-power electrical applications where long life of the energy source is needed, such as implantable medical devices or military and space applications. This could curb the need to build and maintain expensive repository for the radioactive waste lifetime, reduce the risk of leaking into the earth, cheaper and more powerful iterations of betavoltaic cells become feasible.

The experiment aimed to investigate: -

a. Power and potential difference needed to light up a Light Emitting Diode (LED).
b. Power and potential difference of Pm-147 nuclear waste as beta source for a betavoltaic cell.
c. The differences in potential difference and power induced by different electrode material.
d. The changes to betavoltaic cell performance when an alpha source is introduced.

2. Methodology

The electrolyte is Pm-147 which is a solid metal under standard conditions that makes it easy to manage and use for experimentation. A digital multimeter is used to measure potential difference and electrical current. It is set to 0 - 2000 ± 1 mV and 0 - 2000 ± 1 mA respectively. An exception is made for the reference data set where the settings are 0 - 5 ± 0.001 V and 0 - 5 ± 0.001 A.

2.1 Reference System

A reference circuit is set up as a baseline data for goals needed to be achieved by a cell to light up an LED.

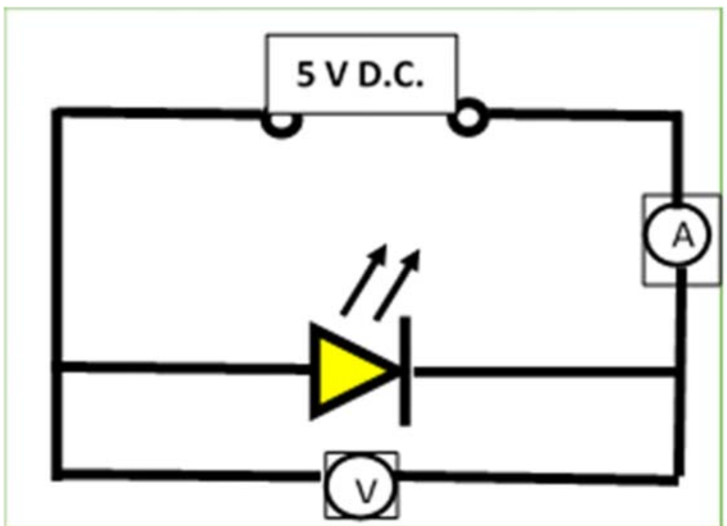

Figure 1: A 5V DC power supply is connected to a circuit with an LED. An ammeter and a voltmeter are connected to the circuit.

2.2 Betavoltaic System

In this experiment, electrode material is manipulated to investigate its effect on the potential difference and power induced in the cell.

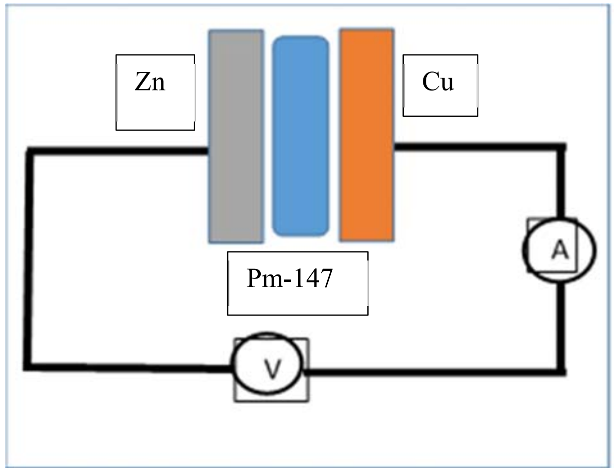

Figure 2: A betavoltaic cell is made up of Pm-147 as an electrolyte and a pair of Zn and Cu as electrodes.

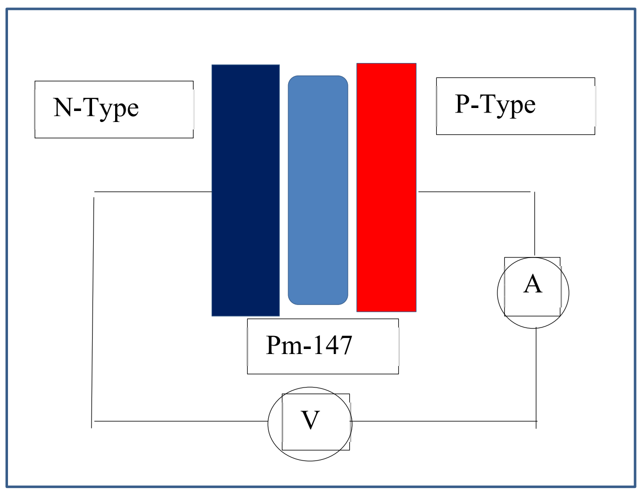

Figure 3: A betavoltaic cell is made up of Pm-147 as an electrolyte and a pair of N-Type and P-Type silicon wafers as electrodes.

2.3 Catalysed Betavoltaic System.

A complimentary particle source is added to a betavoltaic cell could theoretically improve the performance of the cell.

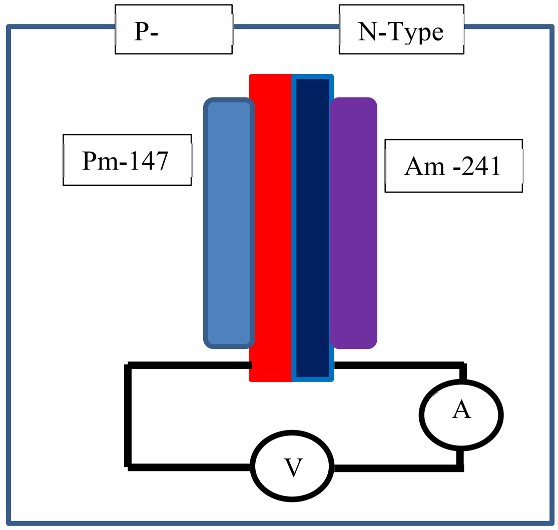

Figure 4: A betavoltaic cell is made up of Pm-147 as an electrolyte and an N-Type and P-Type silicon wafers and it's complimentary as electrodes.

3. Findings And Discussion.

First, the first experiment investigates different electrode material. The data shows electrode material has a significant effect on the output of the cell. The silicon electrode betavoltaic cell shows 25% uplift in the cell output compared to the Cu-Zn electrode betavoltaic cell. The graph shows the best fit line for silicon electrode being higher than Cu-Zn electrode. The possible reason for this, silicon electrode has lower work function than Cu and Zn electrode so it has a higher induction potential which result in a higher potential difference.

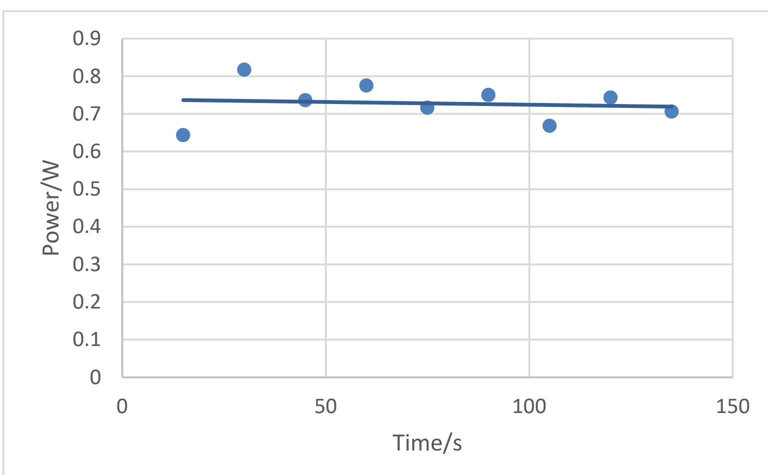

Figure 5: Power needed to light up LED against time.

Next, the second experiment aims to study the effect of an alpha source, Americium-241 (Am-241) as a catalyst to a betavoltaic cell. The data shows a more consistent potential difference induced over time which makes is a good trait for a cell. When compared to the silicon electrode and Cu-Zn electrode cells, the gradient of the graph for potential difference is significantly lower which shows a lower rate of potential difference decay compared to uncatalyzed betavoltaic cell. The line plotted is also higher average in potential difference. This clearly shows an alpha source is accepted as an effective catalyst to the cell; thus, opposite charges of the particle sources can increase the potential difference of the cell.

However, the thickness and density of electrode may play a fundamental role as the silicon electrode was thicker and dense compared to both Cu and Zn electrodes. The silicon electrode was a pair of uncut silicon wafer while Cu and Zn electrode were in the form of thin sheets. The unequal number of atoms to stop beta particle may affect the rate of attenuation which contributes to the potential difference of the cell. To rectify this, equal thickness in number of atoms should be used to determine the potential difference of the cell when varying the electrode material.

Furthermore, the shape of the cell will affect how much particles that pass through the electrode to induce current. In the experiment, two configurations of electrodes were used, a) *electrode sandwich the electrolyte* and b) *source sandwich the electrode*. This is done due to silicon wafers had to form a P-N junction to function as electrodes which makes it act like a diode. It is noticed that the cell still operated like an electrode at low voltages which is lower than is operational voltage to become a conductor. The likely reason is that the electrons emitted and induce current is from a point like source so it is quickly impeded by resistance and hysteresis but sufficient to overcome the band gap in the junction.

Overall, the result support the initial predictions and aim of the study, regarding betavoltaic cells and the ability of nuclear waste to do useful work.

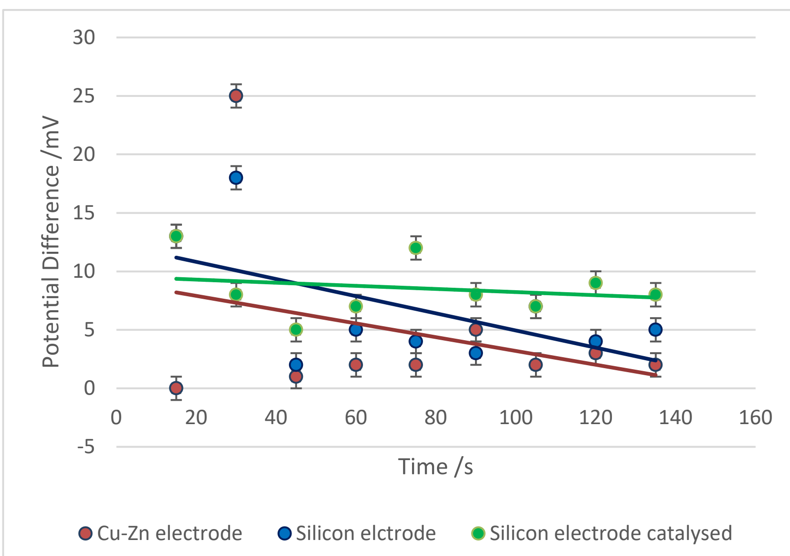

Figure 6: Comparison between Catalysed cell vs Type of electrodes.

4. Conclusion

As a conclusion, nuclear waste is a viable radioactive source of energy in betavoltaic cell. A betavoltaic cell can be made to have different electrode materials that will alter the effectiveness at converting the radiation into energy. Betavoltaic cell does not require expensive and delicate electrode materials like doped silicon wafers to produce an output. Betavoltaic cell output can be catalysed with opposite charge particle source. Nuclear waste like Pm-147 and its catalyst Am-241 is shown to produce significant output compared to uncatalysed betavoltaic cell. This study indicate that the presence of catalyst can reduce the effect of potential difference decay due to decaying activity of radioactive sources.

5. Acknowledgement

Special thanks to Mr. Shahrulnizam Mohamed Kamil, the Head of Science Department of MJSC Serting for facilitating me through this project and the officers at Malaysian Nuclear Agency (Ms. Nurhasfazilah, Mr. Muhammad Khairul Ariff Mustafa, Mr. Naim Syauqi Hamzah, Mr. Muhammad Khairulezwan Abdul Manan and Mr. Mohamad Radzuan Othman) which had helped on performing research and experiments on radioactivity.

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3. Positron Dynamics - www.positrondynamics.com/
4. PH 0101 Unit-5 Lecture-81 Introduction Type of Converter in Nuclear cell Types of Nuclear cell Betavoltaic cell Thermocouple based nuclear cell – https://slideplayer.com/slide/7091349/
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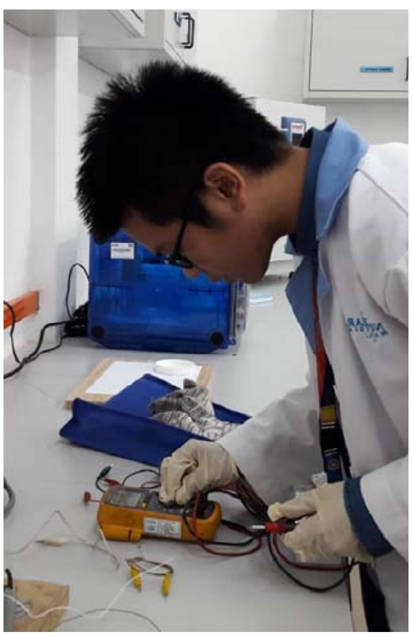
6. https://www.large.stanford.edu/courses/2013/ph241/harrison2/

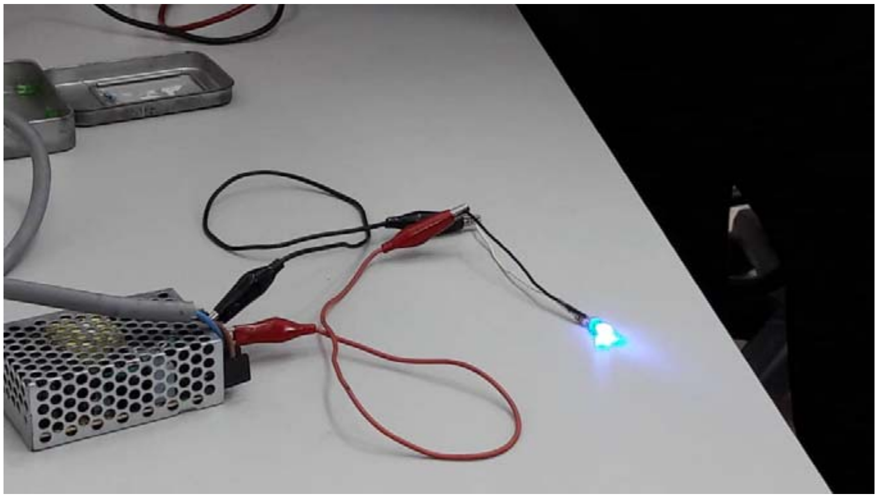
Gallery

From left to right: Am-241 samples (stored in wooden container together with black metallic disks) and a package of Pm-147.


The sample was taking out from a shielded canister (left) and then was weight using a balance (right).




Calibration for digital multimeter used in collecting data.

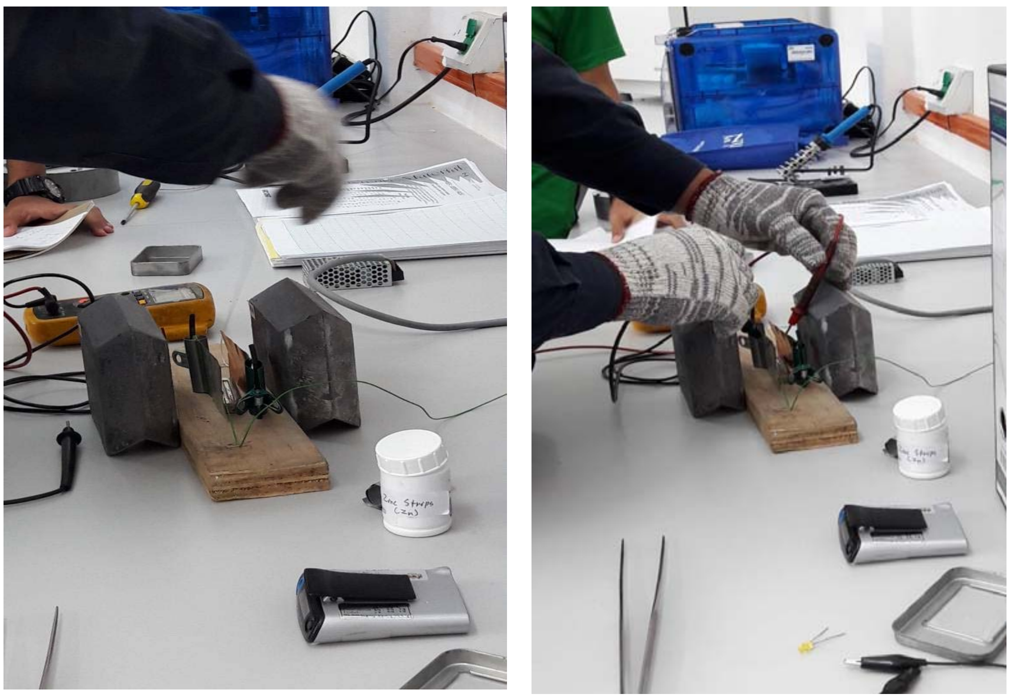


Reference circuit apparatus setup.

Setup of Cu-Zn electrode for betavoltaic cell.

Testing the effect of alpha-beta sources in direct contact.

Setting up the silicon electrode betavoltaic cell.



Lead blocks used as reflectors and blockers during the experiment.

THE SUCCESS OF iNuSTEC2021 CONFERENCE

Nur Syazwani Mohd Ali
Institute Nuclear Engineer MNS
Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia

A three days virtual conference of International Nuclear Science, Technology and Engineering Conference 2021 (iNuSTEC2021) was hosted by Universiti Teknologi Malaysia (UTM) and Malaysian Nuclear Society (MNS) on 10 - 12 October 2021. With the special theme of "Nuclear Science and Technology for Socio-Economic Development", the conference had gathered around 30 - 50 scientists, researchers, and interested parties from Malaysia, China, South Korea, Japan, Austria, and Pakistan. They shared experiences, knowledge, and new findings on nuclear and radiation-related technologies. iNuSTEC2021 was officiated by the Vice Chancellor of UTM, Professor Datuk Ts. Dr. Ahmad Fauzi Ismail. He hopes that the conference will promote research collaboration between the participants. The conference was broadcasted live for the public via MNS's Facebook and Youtube Page.

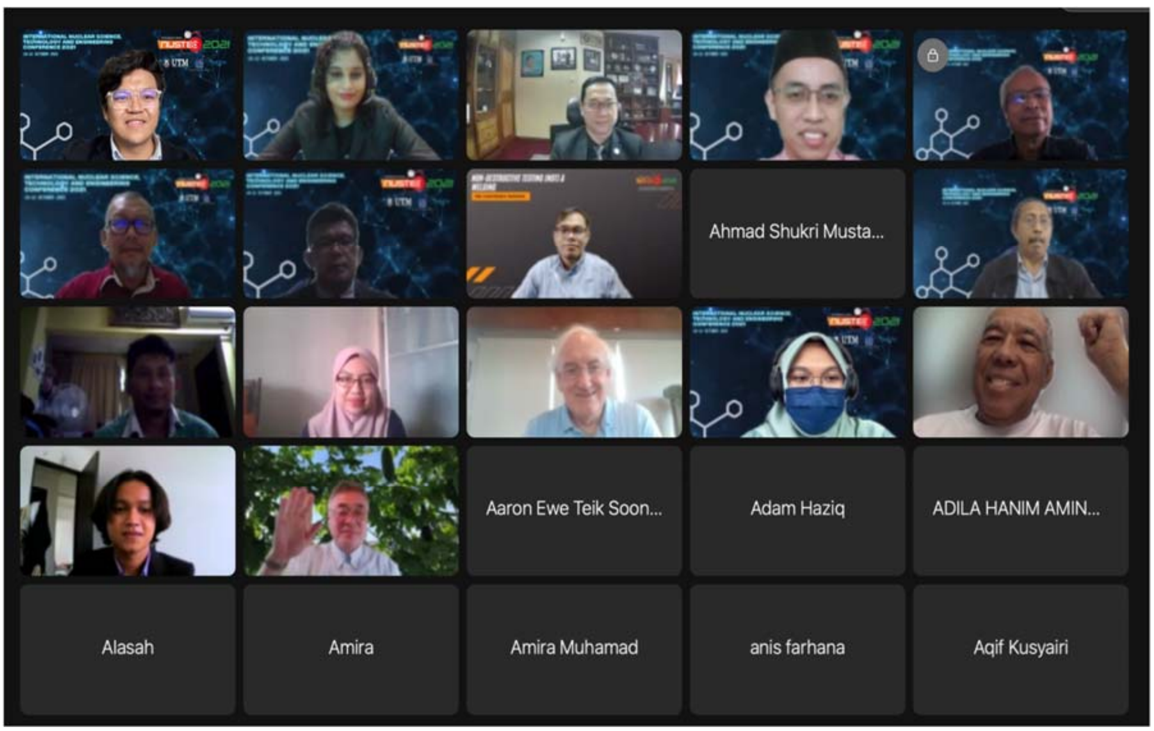


Figure 1. Opening ceremony of iNuSTEC2021.

A total of 32 oral presentations and 5 posters were presented during the event. 19 papers had been selected and published in the IOP Conference Series: Materials Science and Engineering (Volume 1231) which is an open-access journal hosted by IOP Publishing. Topic themes covering from science, engineering, material sustainability, and environmental safety.

Table 1: The details of technical papers published in IOP Conference Series.	
Theme	**Nuclear Science and Engineering**
1.	Model predictive and fuzzy logic controllers for reactor power control at Reaktor TRIGA PUSPATI;
2.	Lattice Design of a Compact Hadron Driver for Cancer Therapy;
3.	Multiprocessing implementation for MCNP using Python;
4.	New exposure room shielding incorporated with ferro boron concrete for neutron radiography imaging (NURI) facility at TRIGA PUSPATI Research Reactor;
5.	Numerical solution of deuteron potential depth using python;
6.	A comparative photon shielding properties of protective Window materials by using EGS5 code;
7.	Evaluation of scattering effects for radiation shielding or filter materials by using Monte Carlo simulation;
8.	Physical properties of polyvinyl alcohol (PVAL) gel materials as phantoms for mammography.
Theme	**Material and Sustainability**
9.	Superconducting properties of $(Bi,Pb)_2Sr_2Ca_2Cu_3O_x$ (BSCCO-2223) superconductor ceramics prepared by conventional solid-state reaction and co-precipitation methods;
10.	Polyethylene composite with boron and tungsten additives for mixed radiation shielding;
11.	Correlation of ground penetrating radar and nuclear density gauge data to determine the density of asphalt pavement;
12.	The effect of various electrospinning parameter and sol-gel concentration on morphology of silica and titania nanofibers;
13.	Fabrication of magnetic sugarcane bagasse paper and Mechanical properties;
14.	Thermogravimetric analysis of peroxide prevulcanized natural rubber latex induced by Co-60 γ radiation.
Theme	**Environmental and Safety**
15.	Time-dependent reliability analysis for a critical reactor safety system based on fault tree approach;
16.	Nuclear fuel materials and its sustainability for low carbon energy system: A review;
17.	Assessment of rare earth and actinides (U and Th) elements in soil samples from Kapar industrial area, Selangor;
18.	Small beam dosimetry by using Al2O3 optically stimulated luminescent (OSL) dosimeters at high energy photons and electrons;
19.	Applying empirical method for performance metrics measurement of a nuclear security system.

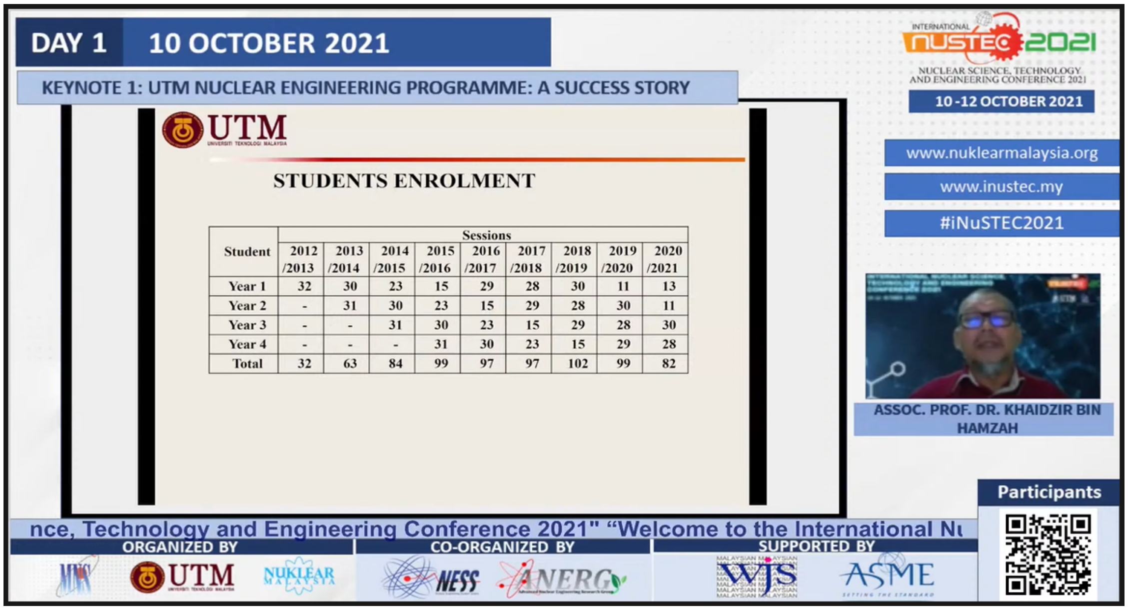


Figure 2. Live broadcast of keynote speech delivered by Assoc. Prof. Dr. Khaidzir Hamzah.

Concurrently, Debat Nuklear Antara Varsiti 2021 and Nuclear Youth Competition (NYC) 2021 events were successfully organized by the Nuclear Engineering Student Society (NESS, UTM) and Advanced Nuclear Engineering Research Group (ANERGy). Both events had attracted a number of teams from four local universities. The debate involved topics such as application of nuclear technology in Malaysia, climate change, and the future of nuclear power generation in Malaysia. The main objective of both events was to encourage students to increase their knowledge on nuclear applications as well as the advantages of nuclear technologies in Malaysia. Congratulations to Universiti Tenaga Nasional (UNITEN) for winning the debate competition. On the other hand, the NYC is a yearly event that pits several teams of undergraduate students in presenting various topics related to nuclear issues. This time around, the winning university team was from UTM. A big round of applause for their efforts! May the involvement of these students will help in seminating the correct information of nuclear technology among the youths in this country.

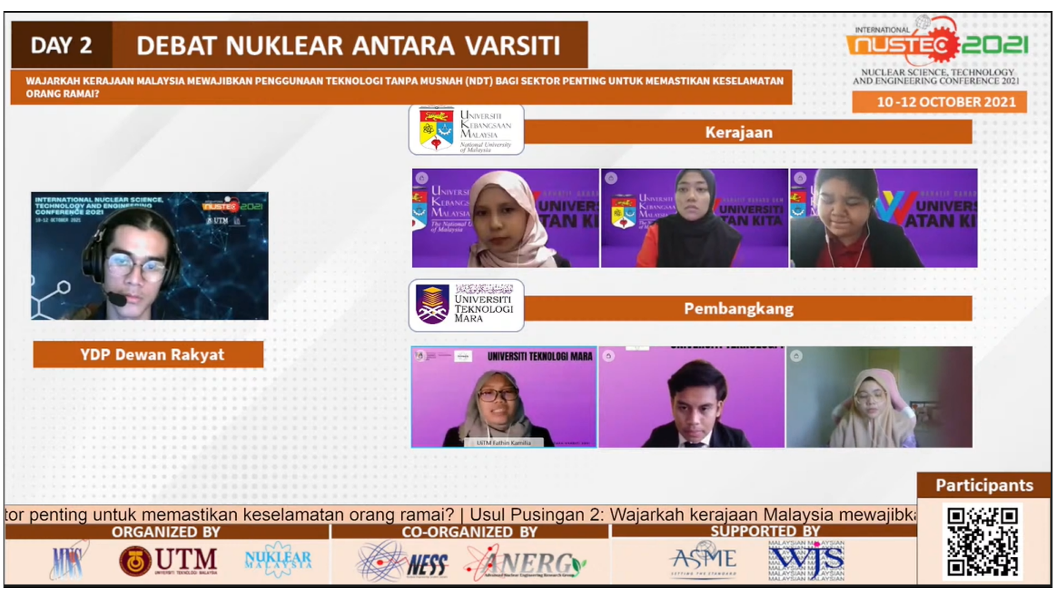


Figure 3. Debat Nuklear Antara Varsiti 2021.

In conjunction with iNuSTEC2021 event, the Pre-Conference Webinar on Non-Destructive Testing (NDT) and the Post-Conference Workshop on Neutronic Simulation was held on 9 and 13 October 2021, respectively. The NDT webinar was delivered by experts from UTM, Malaysian Nuclear Agency (MNA), Malaysian Welding and Joining Society (MWJS), ZL Technologies, and Eddyfi Technologies. Meanwhile, the neutronic simulation workshop was conducted by Dr. Mark Dennis from MNA, Dr. Arif Sazali from UTM and Dr. Hairie Rabir from Universiti Kebangsaan Malaysia (UKM). They are among the neutronic simulation experts in Malaysia. Both events had remarkable participation from various companies and higher learning institutions.

Despite the Covid-19 pandemic, the virtual iNuSTEC2021 and the concurrent events were successfully organized and fulfilled its objectives. The closing remark was delivered by Dean of the Faculty of Engineering, Professor Ts. Dr. Ruzairi Abdul Rahim. UKM will host iNuSTEC2022 on 25 – 27 October 2022. The announcement was officially made by President of MNS, Associate Professor Dr. Abdul Aziz Mohamed.

Figure 4. Closing ceremony of iNuSTEC2021.

iNuSTEC2020, ANOTHER SUCCESSFUL EVENT BY MNS, UNITEN AND MALAYSIA'S NUCLEAR COMMUNITY

Hassan Mohamed
Universiti Tenaga Nasional, Kajang, Selangor, Malaysia

The International Nuclear Science, Technology and Engineering Conference 2020 (iNuSTEC2020) was held from 17 to 19 November 2020 with a special theme of "Sustainable Nuclear Science and Technology for Well-Being of Mankind." The annual Malaysia Nuclear Society's (MNS) conference was jointly organized by Universiti Tenaga Nasional (UNITEN) and Malaysian Nuclear Agency (Nuclear Malaysia) in collaboration with several local universities and industry partners.

The three-day virtual conference has gathered more than 70 participants from Malaysia and nuclear experts overseas, such as the Republic of Korea, the United States of America, and Germany. The event was also streamed live by the Skuad Media (SMU) UNITEN to thousands of online viewers through the MNS YouTube channel. The conference was officiated by Prof. Dato' Ts. Dr. Mohd Zamri Bin Yusoff, the Deputy Vice Chancellor of UNITEN.

In conjunction with the conference, MNS and Arey Solutions Sdn. Bhd. also organized Radiation Safety Refresher course for Radiation Protection Officer (RPO) on 18 and 19 November 2020. The refresher course was specially conducted for RPOs registered with the Atomic Energy Licensing Board (AELB) of Malaysia. On the 2nd and 3rd day of the conference, MNS organized Inter Varsity Nuclear Debate 2020. UNITEN's debate team won the final round of the debate competition. The competition has brought together local university students, especially the young nuclear generation, to discuss issues related to the nuclear landscape, technology and development.

The conference was officially ended by the closing remarks from Dr Siti A'iasah Binti Hashim, the Director General of Nuclear Malaysia. The conference was a successful event as 39 papers have been accepted to be published in the conference proceeding. The next conference, iNuSTEC2021, will be hosted by Universiti Teknologi Malaysia (UTM) Skudai, Johor, from 10 to 12 October 2021.

Figure 1. *Officiating speech by Prof. Dato' Ts. Dr. Mohd Zamri Bin Yusoff, Deputy Vice Chancellor UNITEN.*

Figure 2. *Welcoming speech by Dr. Abdul Aziz Mohamed, President of MNS.*

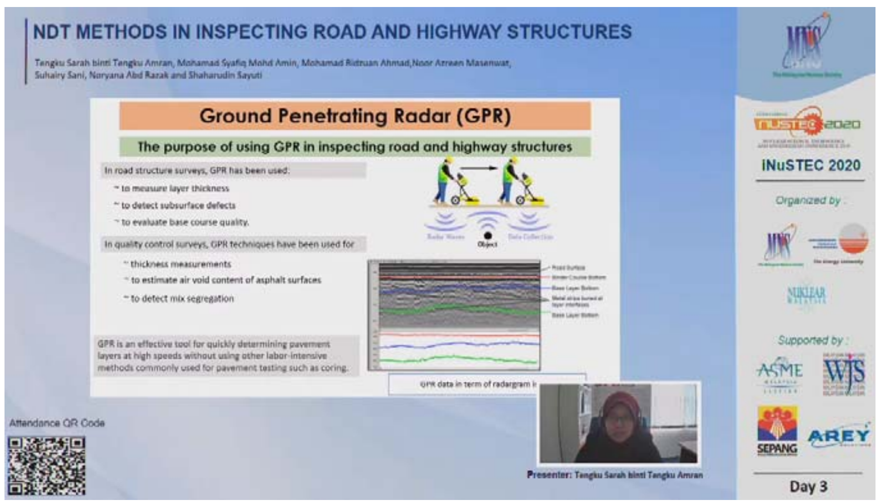


Figure 3. *Presentation by one of the iNuSTEC2020 participants.*

Figure 4. *The final round of the InterVarsity Nuclear Debate 2020 between UNITEN and UiTM with nuclear expert judges.*

Figure 5. The conference was officially ended by the closing remarks from Dr Siti A'iasah Binti Hashim, the Director General of Nuclear Malaysia.

Figure 6. Skuad Media UNITEN (SMU) team has been very supportive and professional in providing technical support during the conference.

A PRELIMINARY QUANTITATIVE STUDY ON THE ECONOMIC IMPACTS OF DEPLOYING A NUCLEAR POWER PLANT IN MALAYSIA USING EMPOWER

Sharvesh Kumar Sreetharan, Mohd-Syukri Yahya*, Nasri A. Hamid
College of Engineering, Universiti Tenaga Nasional (UNITEN), Selangor
* Corresponding author: syukri@uniten.edu.my

Introduction

30th September 2019 marked the sad and disappointing end to Malaysia's latest nuclear ambition when Malaysia Nuclear Power Corporation (MNPC), the Nuclear Energy Programme Implementing Organisation (NEPIO) dedicated to steer the national nuclear power program, was officially closed by the then Pakatan Harapan (PH) government. It was bitterly disappointing because all efforts – financial, manpower, time – invested since 2009 had to be unceremoniously shelved despite the fact that we were already in Phase 2 (decision making phase) of the International Atomic Energy Agency (IAEA)'s infrastructure development program for the newcomer countries [1]. It was heartbreakingly sad when all project outputs – cabinet papers, feasibility study reports, research findings – were blindly ignored by the then PH government as MNPC was not offered any forum to share the lessons learned despite being internationally recognized by the IAEA as a model NEPIO for the newcomer countries. It seemed that the ten-year efforts at preparing Malaysia for a safe and sustainable nuclear power deployment was, simply and completely, cancelled.

What made the decision to disband MNPC more frustrating was the fact that it was chiefly due the promise proclaimed in the 2018 PH Buku Harapan: "the UMNO and Barisan Nasional's efforts to build nuclear power plants will be stopped" (the PH government did just that!). This decision, therefore, felt very politically motivated. To the authors, *this* was neither the right way forward nor the right approach to govern a nation. Any policy decision, especially that concerning a national interest such as our energy of choice, should always be apolitical – free from political pressure and be objectively based on situational merits. As nuclear is the only *proven* low carbon baseload power generation technology, we strongly believe nuclear energy should remain an option for Malaysia despite any election manifesto.

It is upon this conviction that this research paper was prepared: should nuclear option remain on the table; we wondered its direct impacts on our economy. Specifically, we wished to quantitatively evaluate the direct consequences of deploying nuclear power on Malaysia's macroeconomic parameters using the IAEA-developed EMPOWER spreadsheet. It must be noted that the authors are neither economists nor are we pretending to be one; this preliminary study was simply an academic exercise at using EMPOWER and was built on a previous study funded by the MNPC [2]. Values presented in this paper were thus limited by our assumptions and EMPOWER modelling constraints. The results, nonetheless, still offer valuable insights for an informed future decision should Malaysia determine to pursue nuclear power again.

The IAEA's EMPOWER Spreadsheet

EMPOWER (the Extended Input-Output Model for Nuclear Power Plant Impact Assessment) is a Microsoft Excel-based spreadsheet, programmed to quantitatively evaluate impacts of nuclear energy on the key macroeconomic indicators such as employment rate, export levels and the gross domestic product (GDP). EMPOWER was coded in such a way that it would be relatively easy to perform similar assessments on the other types of energy as well. Figure 1 illustrates the graphical use interface of EMPOWER while Figure 2 presents an overview of the mathematical models used in the spreadsheet. Detailed discussions on EMPOWER are available in [3].

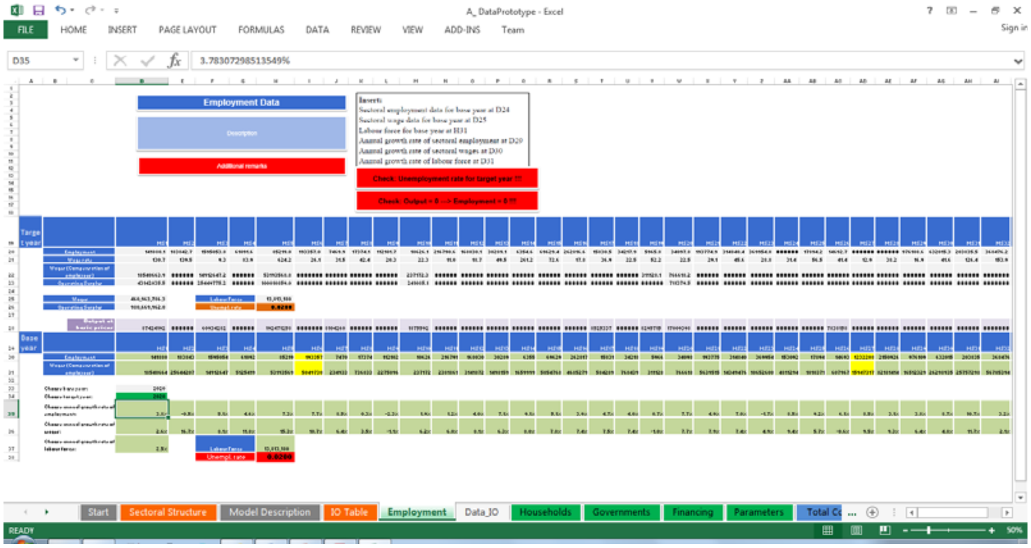
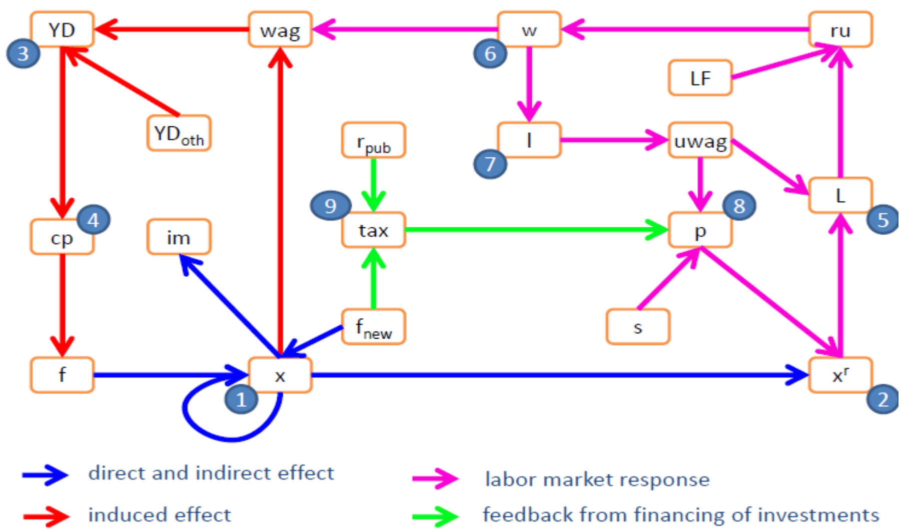


Figure 1: The EMPOWER graphical user interface



(a)

Output (in nominal terms) (1) $\mathbf{x} = \mathbf{A}^d\mathbf{x} + \mathbf{cp} + \mathbf{f}^* + \mathbf{f}^{new}$	Wages (6) $w = \exp(const_w + \beta_{ur}\log(1 - L/LF))$
Output (in real terms) (2) $\mathbf{x}^r = \mathbf{x}/\mathbf{p}$	Unit labour costs (7) $\mathbf{l} = \mathbf{l}_{base} w/(0.5 * w_{base} + 0.5 * w)$
Disposable income (3) $YD = \mathbf{l}wf_{w,hh}(1 - t_{hh})\mathbf{x} + \mathbf{s}f_{s,hh}(1 - t_{hh})\mathbf{x} + YD_{oth}$	Prices (8) $\mathbf{p} = \mathbf{p}\mathbf{A}^d + \mathbf{p}^m\mathbf{A}^m + \mathbf{l}w + \mathbf{s} + \mathbf{t}^q$
Consumption (4) $\mathbf{cp} = [\exp(const_{cp} + mpc(\log(YD))]\mathbf{b}^d_{hh}$	Tax rate (9) $t^{new}_{hh} = \frac{r_{pub}\, \mathbf{i}' \mathbf{f}^{new}}{YD}$
Employment: (5) $L = \mathbf{l}\mathbf{x}^r$	

Four types of multipliers

- direct and indirect effect (equations 1 i 2)
- & induced effect (equations 3 i 4)
- & labor market response (equations 5-8)
- & feedback from financing of investments (equation 9)

(b)

Symbols used:
x - output;
cp - household consumption;
f - final use (excluding household consumption);
p - output prices;
w - wage rate (wag/L);
YD - disposable income (after tax);
YD_{oth} - non-wage income;
L - employment;
LF - labour force;
t_{hh}^{new} - revenue-neutral tax rate.

Symbols written with variables in the upper or lower index:
r - in real terms;
d - domestic;
m - foreign;
* - original data;
base - in base year.

Parameters:
l - unit employment (L/x);
s - unit operational surplus;
A - Matrix of input-output coefficients;
t_{hh} - househlod tax rate;
$f_{s,hh}$ - coefficients for harmonization wages in i-o tables and NA;
$f_{w,hh}$ - coefficients for harmonization wages in i-o tables and NA;
const- constant term;
mpc- marginal propensity of consumption;
β_w - parameter of wage response to unemployment rate.

Other symbols:
log - natural logarithm;
exp - exponential function;
i - unit vector;
' - symbol of transposition;

vectors are marked in bold

(c)

Figure 2: *The EMPOWER mathematical models: (a) the schematic program overview, (b) the generic equations for each respective macroeconomic parameter, and (c) a list of nomenclature for the models [3].*

EMPOWER was programmed on a four-level model: (1) 'Model A' is the standard input-output program to calculate the direct and indirect effects, (2) 'Model A + B' extends 'Model A' by capturing the induced effects from private consumption, (3) 'Model AB + C' extends 'Model A + B' by including the labour market's responses to supply and demand, and (4) 'Model ABC + D' extends 'Model AB + C' by also considering the government feedbacks via public-private financing investments [4].

In order to reasonably predict the macro-economic impacts of constructing and operating a nuclear power plant, various economic datasets were inputted into EMPOWER. All data procured for this study were obtained from the Department of Statistic Malaysia (DOSM), Asia Data Library Data Bank, Institute of Labour Market Information and Analysis (ILMIA) database, MNPC archive and online publications.

The main input data used as benchmark for all calculations was the national input-output table, a matrix of domestic and import data for 35 economic sectors in Malaysia. These sectors were specifically selected and grouped based on their direct or indirect influences on local economy. Data on annual employment and wages, as well as growth rates were also needed. This was followed by data of household economic parameters such as annual wages, operating surplus, income tax and average social contribution. As household economic parameters would directly be affected throughout the operation of the nuclear power plant, the datasets were categorized into most favourable, moderately favourable, and least favourable scenarios.

Other financial and economic parameters required by EMPOWER were external financing percentage, marginal propensity of consumption, wage reaction to unemployment rate, and export price elasticity. Total construction cost distribution throughout the 12-year construction period was sourced from MNPC. It should be noted that the simulation results were very sensitive to the currency exchange rates, especially on the distribution of annual construction cost. In addition, the national annual power consumption of other energy sources, as extrapolated from the National Energy Handbook, were also inputted into EMPOWER. It should also be noted that our simulations did not take into account the socio-economic impacts of COVID19 as our study was completed pre-pandemic.

Findings And Discussion

The study assumed a twin NPP unit was to be constructed in the year 2020. Main macroeconomic indicators of interest are GDP, national output, disposable income, and annual employment. Figure 3 displays impacts of constructing the nuclear power plant on the national GDP. 'Model ABC + D' shows the highest and 'Model A' the lowest GDP contribution. This is because 'Model ABC + D' considers wider economic parameters compared to 'Model A'.

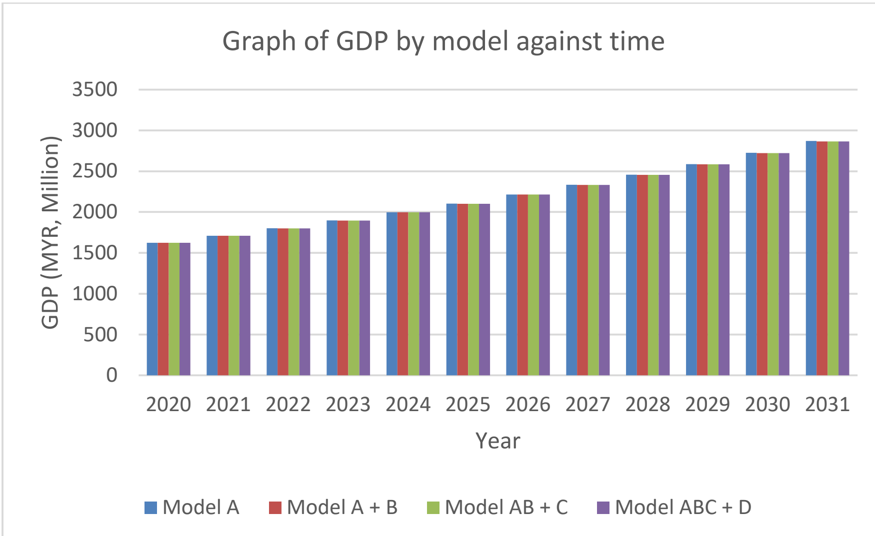


Figure 3: Impacts of an NPP on the national GDP during construction period

Figure 4 shows the national output increment during the construction. National output in this chart represents the sum of GDP and intermediate inputs. Similar to the GDP, output of the nuclear power plant is highest in 'Model ABC + D' and lowest in 'Model A' at the end of the construction year 2031. This is because 'Model A' does not consider factors such as labour market responses, income tax, financing, and investment parameters, which would significantly reduce final output of the nuclear power plant at the end of the construction period.

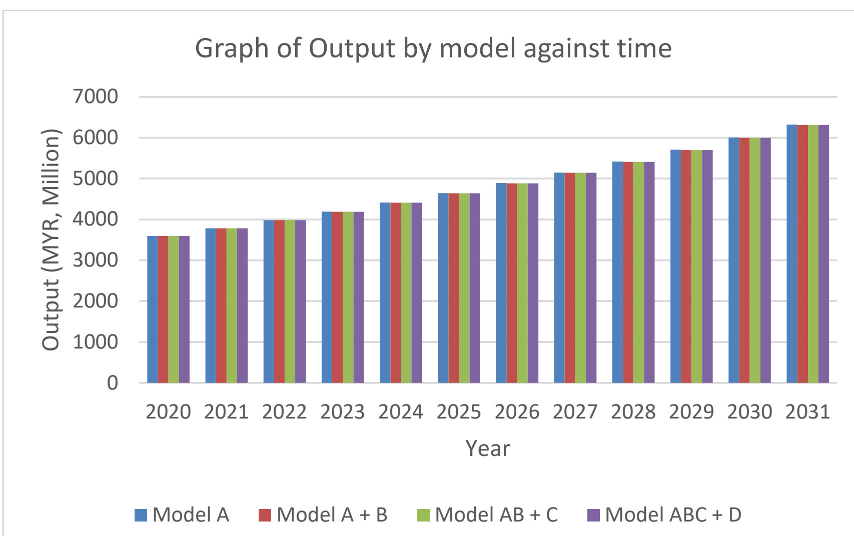


Figure 4: Output of the nuclear power plant during its construction period

Figure 5 shows the national disposable income during the construction period. It should be noted that the disposable income for each model displays similar trend of depreciation throughout. Nevertheless, 'Model A' consistently has the highest disposable income value at the end of the construction period. This is because 'Model A' does not consider factors that directly influence the disposable income such as wages, household expenditure and income tax, which are directly proportional to consumer expenditure per capita and are inversely proportional to the disposable income [6].

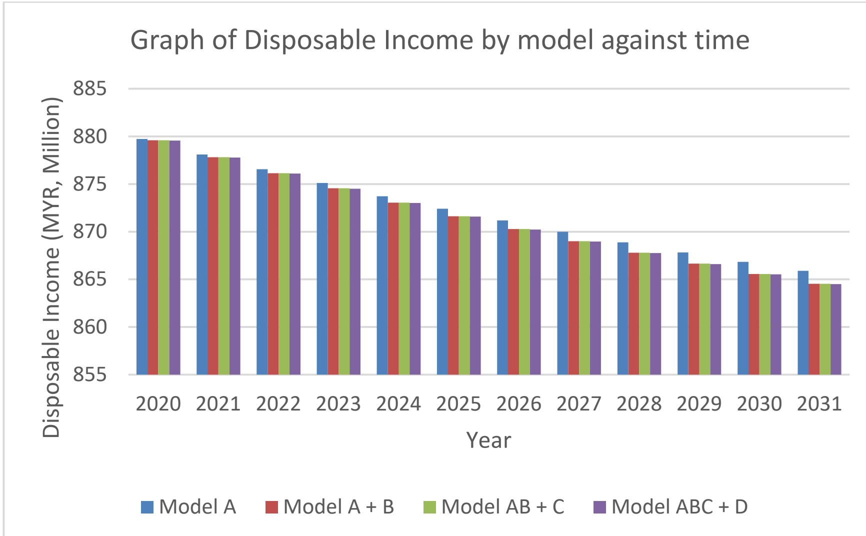


Figure 5: National disposable income throughout the construction period of the power plant

Figure 6 shows annual increment in the local employment during the construction period. 'Model AB + C' and 'Model ABC + D' show constant increments over time, while 'Model A' and 'Model A + B' display some periods of decrement. While demands for skilled labour increase, the required jobs would be highly specific and technical [7]. Skilled labour force would also be necessary to meet any sudden changes in the construction plans and unexpected overnight costs. Since only 'Model AB + C' and 'Model ABC + D' take into account the labour market response, employment by sector and wages by sector, the predicted increment in the employment was expected. On the other hand, 'Model A' and 'Model A + B' predict regressing employment since they exclude the aforementioned considerations.

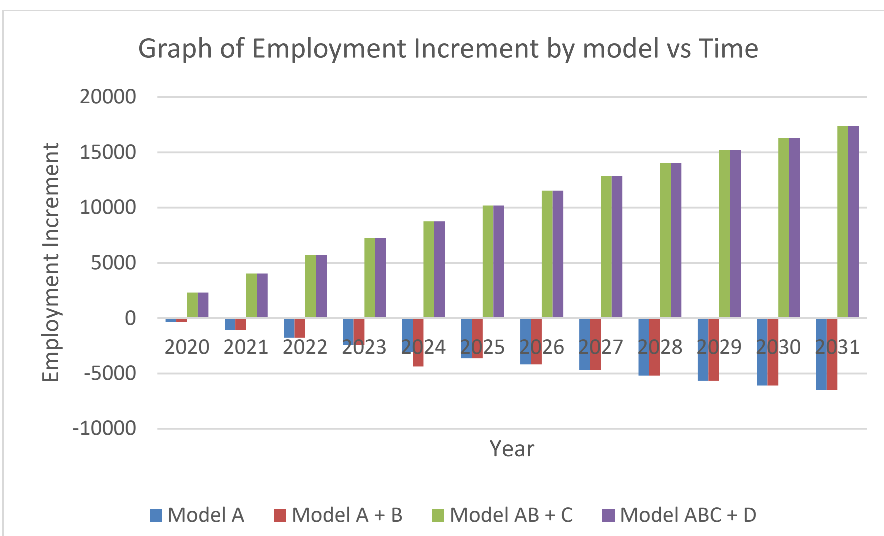


Figure 6: Annual employment during the construction of a nuclear power plant

Figure 7 summarizes the macroeconomic impacts of a nuclear power plant should one commences the operation in the year 2032. 3 scenarios were considered, namely most favourable, moderately favourable, and least favourable. Datasets used to obtain these 3 scenarios were household economic indicators, unique financial parameters, and operation cost output. GDP increment in the most favourable scenario is the highest compared to the other scenarios. It is generally accepted that an investment in nuclear energy would have a positive impact on the GDP due to the interdependence between power consumption and national annual economic growth [8].

Meanwhile, the national output and disposable income in the first year of operation (simulated year 2032) are quite similar in all scenarios since output of the nuclear power plant were about constant [9]. Deviations from the expected annual outcomes may still occur due to scheduled maintenance, outages or reduction in efficiency for a small period of time [10]. The differences in the values between each model would be due to the difference in calculation models; for example, 'Model ABC + D' considers the induced effects of labour market response and feedback from financing and investment, while 'Model AB + C' neglects those feedback from the financing and investment. On the other hand, 'Model A + B' considers the household induced effects such as household income, income tax, social contribution, and operating surplus while 'Model A' uses values directly from the input-output table.

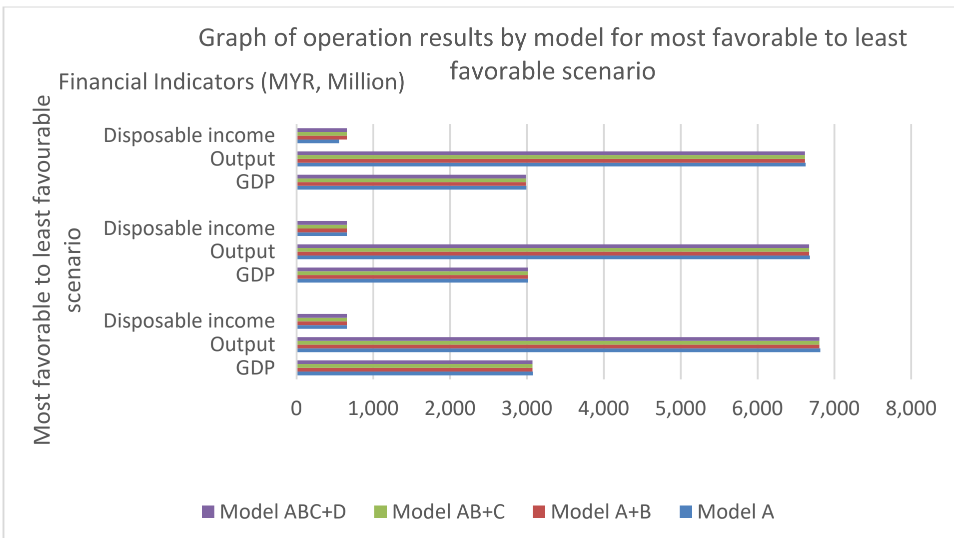


Figure 7: Financial impacts of operating a nuclear power plant in Malaysia

Figure 8 shows impacts on the employment rate by model for the most favourable, moderately favourable, and least favourable scenarios during the first year of plant operation (year 2032). A significant increase in the employment rate can be observed from the last year of construction (year 2031) to the first year of operation (year 2032). This is due to the fact that in order to operate a nuclear power plant, a number of highly qualified personals must be appointed. In the USA, it was found that additional 500,000 jobs per year could be created by just increasing the generation capacity of a nuclear power plant [11].

The predicted values between these scenarios are also quite similar since the simulation was performed during the initial operation period of the nuclear power plant. Nonetheless, 'Model A' displays higher employment rate than 'Model A + B' and 'Model AB + C' because 'Model A' does not consider labour market response, wage reaction to unemployment rate and employment by sector data. These aforementioned parameters negatively affect prospective employment availability due to wage levels and highly specialized technical job requirements. Meanwhile, 'Model ABC + D' predicts an increase in the employment rate because the model takes into account the external financing, export data and investment plans. This reasonably assumes the government and private industries would invest in the nuclear power plants, resulting in the creation of collateral job opportunities such as in the research and development work and consultancy projects.

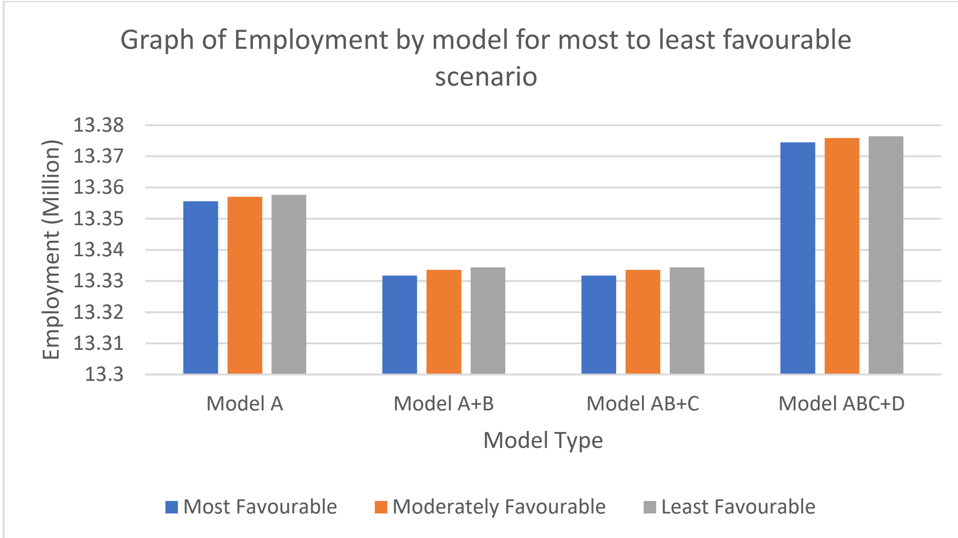


Figure 8: Graph of employment by model for most to least favourable scenario

At the end of the construction period (year 2031), GDP was predicted to be RM2.867 billion, the national output RM6.311 billion, the disposable income RM864.5 million, and the employment opportunity 1.5 million jobs. At the beginning of the operation period (year 2032), twelve years after the start of the construction period (year 2020), the most favourable scenario predicts RM3.071 billion GDP (about +90% from RM1.624 billion in 2020), the national output RM6.806 billion (about +90% RM3.595 billion in 2020) and the disposable income RM654 million (about -25% from RM879 million in 2020).

Conclusion

EMPOWER predicted highly positive impacts of constructing and operating a twin-unit nuclear power station on Malaysia's macro-economic parameters, with almost the doubling of the GDP and national output within the twelve-year period, and significant creations of highly technical and specialized jobs throughout. The study also concluded that the budget of RM31 billion assumed by the previous Malaysia government needs to be revised.

It should be noted that the impacts of deploying nuclear power extend beyond the simulated macroeconomic parameters. Not only embracing nuclear power opens doors for spin-off high-technology industries based on the radiation and clean energy, it also helps cultivate awareness of the highest safety culture. With time, nuclear power can also become our national pride as it helps sow refined appreciation for the scientific knowledge. Most importantly, nuclear power offers the only *proven green* solution to the baseload power generation in order to mitigate the worst consequences of climate change.

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