STUDY OF NEUTRON FIELD AROUND MALAYSIAN NUCLEAR AGENCY-PLASMA FOCUS (MNA-PF) USING PHITS

Puteri Nuraliah Husna Mohd Tajuddin, Mohd Faiz Mohd Zin, Rokiah Mohd Sabri, Abd Halim Baijan, Leo Kwee Wah, Mohd Azhar Ahmad, Mukhlis Mokhtar, Mohammad Karimi Manawir, Mohd Noor Shafeek Jaafar

Accelerator Development Centre, Technical Support Division, Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor, Malaysia

email: puteri@nm.gov.my

ABSTRACT

Plasma Focus is a device that can produce neutron, x-ray, electron, and ion. The Malaysian Nuclear Agency employs a plasma focus device based on the UNU/ICTP PFF design of the Mather type. In this study, the Particle and Heavy Ion Transport Code System (PHITS) was used to model the neutron field in the plasma focus. PHITS is a Monte Carlo particle transport simulation code that was used to model the Malaysian Nuclear Agency-Plasma Focus device and simulate the neutron field in the chamber. As a result of employing the PHITS code, the effective dose rate will be compared with the result from the experiment that has been done to study the neutron field around the plasma focus device. The neutron flux and dose mapping also has been obtained from the PHITS code.

ABSTRAK

Plasma Focus is a device that can produce neutron, x-ray, electron, and ion. The Malaysian Nuclear Agency employs a plasma focus device based on the UNU/ICTP PFF design of the Mather type. In this study, the Particle and Heavy Ion Transport Code System (PHITS) was used to model the neutron field in the plasma focus. PHITS is a Monte Carlo particle transport simulation code that was used to model the Malaysian Nuclear Agency-Plasma Focus device and simulate the neutron field in the chamber. As a result of employing the PHITS code, the effective dose rate will be compared with the result from the experiment that has been done to study the neutron field around the plasma focus device. The neutron flux and dose mapping also has been obtained from the PHITS code.

Keywords: Plasma focus, PHITS, effective dose rate

INTRODUCTION

The plasma focus device is a device that converts energy from the capacitor into energy that can move the current sheet and form a plasma (A.B. Blagoev, 2013). The plasma focus consists of three phases in discharge the plasma focus. The first phase is inverse phase or also known as lift-off phase. This is where the electromagnetic force was produced due to the interaction of current and azimuthal magnetic field. The current filaments will be pushed radially outwards leaving the insulator surface and forming a cylindrical current sheet. The inverse phase will end when the current sheet reaches the outer electrode and forms an annular structure (C.S. Wong, 2002). Second phase is the axial acceleration phase. This phase starts when the current sheet moves towards the open end of electrodes under electromagnetic force and ends when the current sheet reaches the end of the electrode (A.B. Blagoev, 2013). Last phase is the radial compression phase. This phase occurs when the current sheet continues being pushed out the electrodes thus creating an additional dimension that electromagnetic force can be acted upon and formed a plasma (C.S. Wong, 2002).

The Plasma Focus has been used in many countries including Britain, Russia, China, Argentina, Singapore, United State, India, Pakistan, and Malaysia (Singh et al., 2022). In Malaysia, MNA-PF consists of a capacitor that can store energy up to 30µF with rated voltage of 15kV (Zin et al., 2017). Plasma focus devices can be used in many applications, so it is better to understand the fundamental process of the plasma. The applications that can be explored using Plasma Focus Device are activation analysis, neutron radiography and actinide waste reduction (Kenneth W. Struve & Bruce L. Freeman, 2012). Most of the researchers were attracted by the Plasma Focus Device because of the powerful short impulse of fast neutrons and x-rays that produces inside the chamber that can be used as a source to solve scientific and technical problems (Zhukeshov et al., 2019).

A plasma focus device can generate ions, electrons, neutrons, and x-ray in the form of pulsed (Zin et al., 2017). Those pulsed can be created when high voltage from coaxial cylindrical electrodes that were separated by an insulator applied to the low-pressure gas (Zanelli et al., 2018). Gases used in the chamber of the plasma focus device will determine the type of atoms that are produced. Neutrons can be produced by using deuterium as operating gas (C.S. Wong, 2002). The neutron field has been simulated for a neutron with energy of 2.45 MeV and 14.1 MeV using PHITS code (Rahmani, 2016). The energies were obtained due to the reaction of Deuterium-Deuterium (D-D) and Deuterium-Tritium (D-T) reaction (Lang et al., 2018). Besides that, electrode geometry plays a big role in determining the neutron production (Akel et al., 2021). Due to this reason, the effective dose rate from this simulation has been compared to the experiment that has been done before in the paper of *Preliminary results of Malaysian Nuclear Agency Plasma Focus (MNA-PF) as a slow focus mode device for deuterium filling gas in correlation with Lee model code* (Zin et al., 2017).

MATERIALS AND METHODS

This work required the Particle and Heavy Ion Transport code System (PHITS) to run the simulation that has been used in many studies that includes the study of radiation. PHITS can be used to simulate the transport of all particles that include the neutron field in the plasma focus (Sato et al., 2018). The first step in starting using the PHITS is to define the geometry and the source used in the Plasma Focus Device. The geometry of the Plasma Focus device can be obtained by measuring the Malaysian Nuclear Agency-Plasma Focus (MNA-PF) device that has been located at Block 43T, Malaysian Nuclear Agency. The measurement required the plasma focus to be dismantled as all components needed to be measured.

Figure 1 shows a schematic view of MNA-PF. The diameter of the chamber is 20.2 cm and 24 cm in height with thickness of stainless steel of 0.7 cm. Inside the chamber as in Figure 2, there are six brass rods of cathode with diameter and height of 0.94 cm and 15.7 cm respectively. There is also an anode in the middle of the chamber that was made up of copper with dimensions of 2 cm for diameter and 15 cm for height. There is Pyrex glass at the bottom of the anode that acts as an insulator. The Pyrex glass has a dimension of 2.59 in diameter with height of 2.5 cm.

Next step is to determine the source in the MNA-PF. Plasma focus device is a device that does not require any radioactive source. But in this work, it was assumed that the neutron is produced due to the D-D reaction inside the chamber. D-D reaction is the collision of plasma with the deuterium gas. The neutron has 7500 neutrons/shot in the Source section. This follows the neutron produced during experiment as in the paper of Preliminary results of Malaysian Nuclear Agency Plasma Focus (MNA-PF) as a slow focus mode device for deuterium filling gas in correlation with Lee model code (Zin et al., 2017). The neutrons are usually captured by using a Portable Spectroscopic Neutron Probe. The dimension for the probe is 5 cm for diameter and 5 cm for length (Ing et al., 2007). The probe has been located at the top of the plasma focus device.

Figure 1. Outer view of MNA-PF

Figure 2. Inner view of MNA-PF

The T-Track was used in the PHITS to obtain the neutron flux, effective dose rate and dose mapping in the plasma focus device. The T-Track has been set to convert the unit from pSv/sec to µSv/hr to obtain the effective dose rate. The spectrum of the effective dose rate has been shown in the results. The history number per batch, maxcas and number of batches, maxbch has been set high to lower the relative error. This is because the uncertainty depends on the total history number. The results have been reported with relative error of less than 5%.

RESULTS AND DISCUSSION

Geometry of MNA-PF

First result shows the geometry of the MNA-PF from the X-Z axis. From the geometry it shows that the deuterium gas has filled up the chamber of the plasma focus. The detector has been placed at the top of the MNA-PF. There are six cathodes that have been placed around the anode in the middle. The Pyrex that acts as an insulator has been placed at the bottom of the anode. Figure 3 shows the X-Z (front) view of the MNA-PF. While Figure 4 shows the X-Y (top) view of the MNA-PF. Figure 5 shows the three dimensions (3-D) of the MNA-PF. At the tip of the anode, strong magnetic compression occurs those results in the formation of a dense plasma column. The plasma column collapses when instabilities occur. When plasma is being pinched and collapses, intense radiation and beams of particles are emitted (Jain et al., 2021).

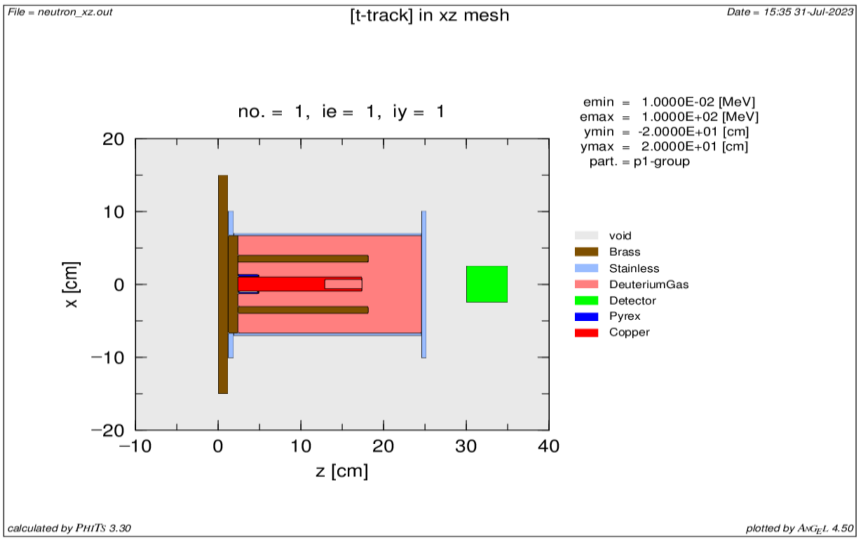

Figure 3. X-Y (front) view of the MNA-PF

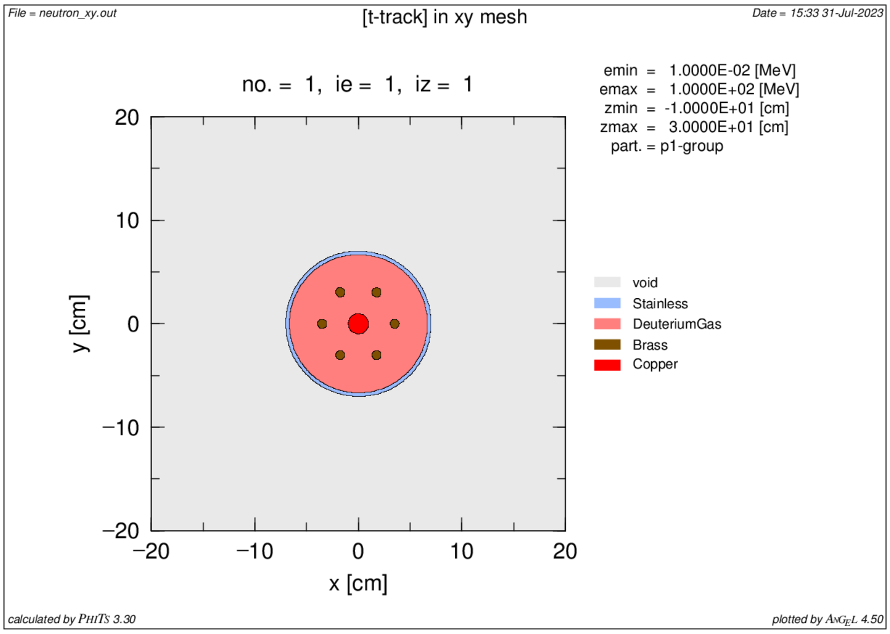

Figure 4. X-Y (top) view of MNA-PF

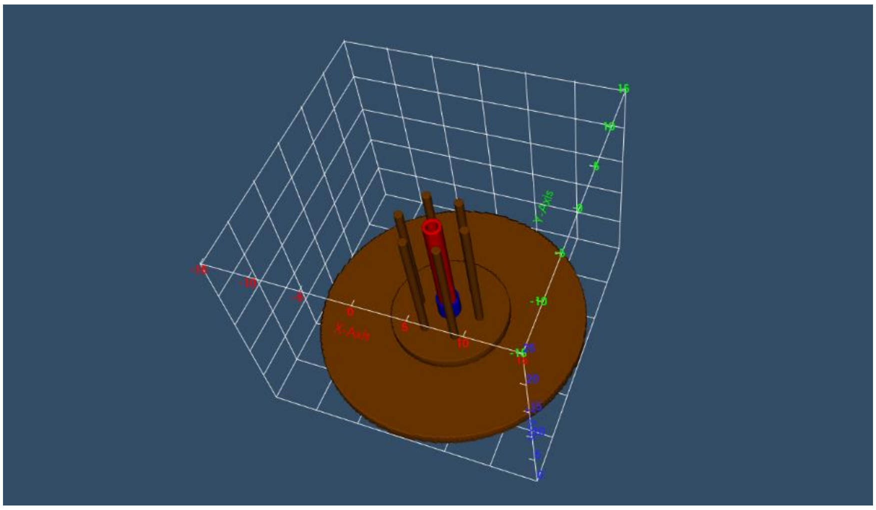

Figure 5. Three dimensions (3-D) view of the MNA-PF

Effective Dose Rate

The effective dose rate that has been obtained from the T-Track tally is 4.326 µSv/hr. This result, when compared to the result in the previous study which is 4.78 µSv/hr is almost the same. This proves that the calculation and experimental data from previous study can be used. Thus, the neutron yield that has been obtained from previous study which is 7.5E+03 can be used in the further study. Figure 6 shows that the effective dose rate is highest when the energy reaches 2.45 MeV and 14.1 MeV. Figure 7 also shows that the fluxes are highest when energies are 2.45 MeV and 14.1 MeV. These are the energies of neutrons that have been used in the code. When the energy reaches 2.45 MeV, the effective dose is 3.7033 µSv/hr and the flux is 2.3515E+02/cm^2/source. While, when energy reaches 14.1 MeV, the effective dose rate is 4.3569E-02 µSv/hr and the flux is 2.4103E+00/cm^2/source. These results show that energy of 2.45 MeV affected most of the total effective dose rate and flux of neutrons. From PHITS, the average relative error is 4%. Thus, these results can be accepted.

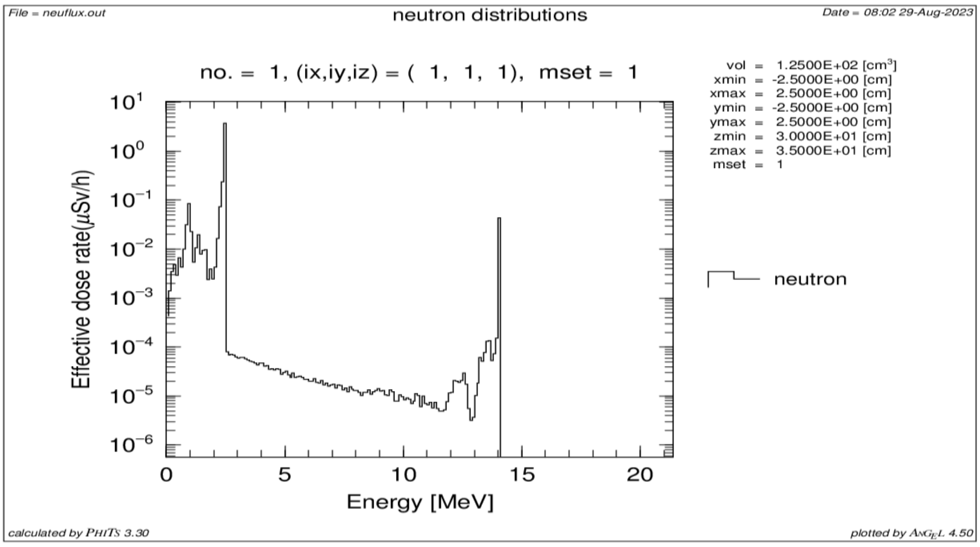

Figure 6. Effective dose rate VS Energy for MNA-PF

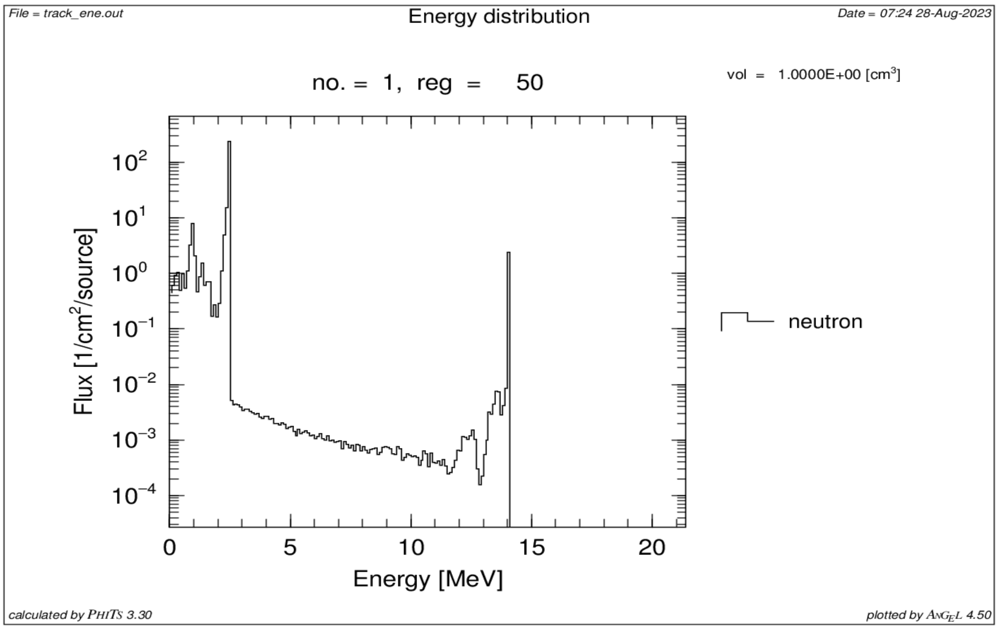

Figure 7. Flux of neutron VS Energy

Dose Mapping

From the PHITS code, the dose mapping has been shown as in Figure 8 and Figure 9. From these two figures, it shows that the highest effective dose rate has been located at the tip of the anode. This is a location of neutrons that have been produced due to the pinching of plasma.

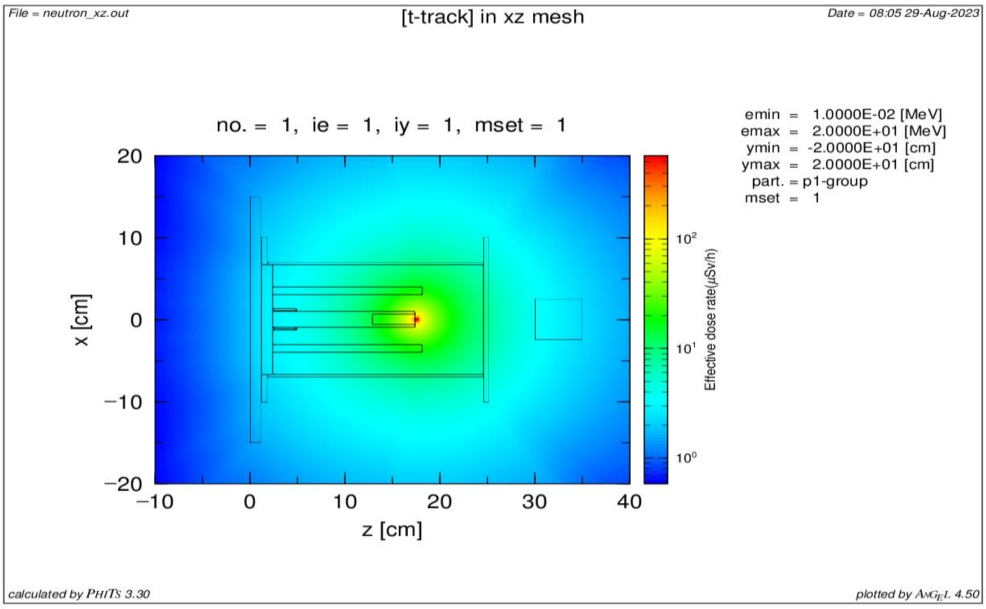

Figure 8. Dose mapping in XZ mesh

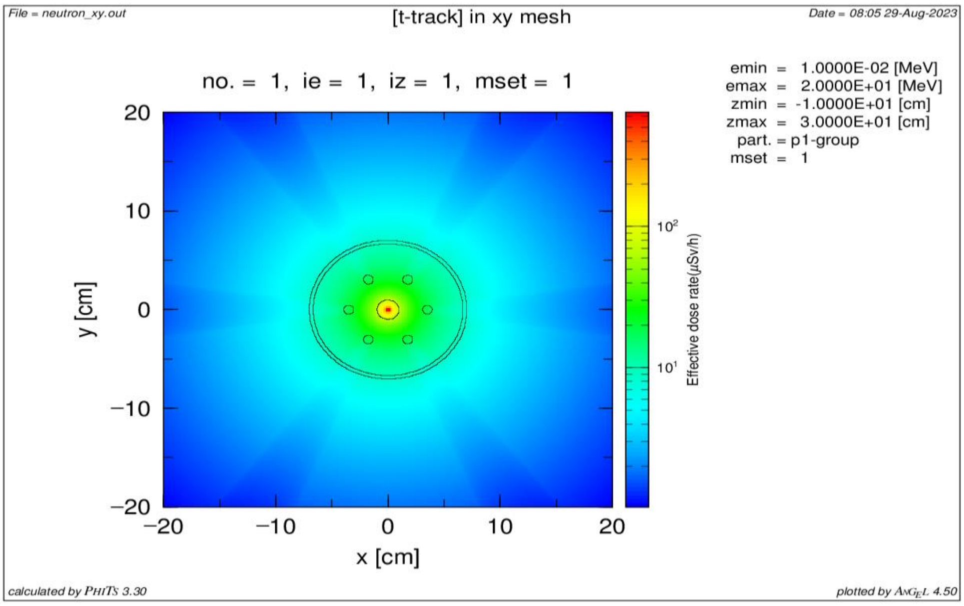

Figure 9. Dose mapping in XY mesh

CONCLUSIONS

The effective dose rate, dose mapping, and neutron flux for MNA-PF have been obtained by using PHITS code. The result for effective dose rate has been compared with the result that has been published in Preliminary results of Malaysian Nuclear Agency Plasma Focus (MNA-PF) as a slow focus mode device for deuterium filling gas in correlation with Lee model code. The previous work has been done via experiment and calculation. From the result in the PHITS code, the effective dose rate obtained was almost the same as the result that has been done through experiment which is 4 µSv/hr. The average relative error from PHITS is 4%, which is lower than 5%.

This error can be reduced more by increasing the number of batches and number of histories per batch. Therefore, it can be confirmed that the measurement neutron dose that emitted from MNA-PF is around 4 µSv/hr when the neutron yield from previous calculation and experiment has been used in the PHITS code.

ACKNOWLEDGEMENT

The authors would like to thank the ADC members for their help during the measurement of the Malaysian Nuclear Agency-Plasma Focus (MNA-PF). The ADC members also help me in writing the code, analysing, and writing the paper. I would like also thanks Japan Atomic Energy Agency (JAEA) for giving me license to use the PHITS code to support my research in the plasma field.

REFERENCES

A.B. Blagoev. (2013). Investigation of the Dense Magnetized Plasma Created by Plasma Focus Device. In *Integrated Approach to Dense Magnetized Plasmas Applications in Nuclear Fusion Technology: Vol. IAEA-TECDOC-1708*. International Atomic Energy Agency.

Akel, M., Kubes, P., Paduch, M., & Lee, S. (2021). Comparison of measured and computed neutron yield from PF1000 plasma focus device operated with deuterium gas. *Radiation Physics and Chemistry*, *188*, 109633. https://doi.org/10.1016/j.radphyschem.2021.109633

C.S. Wong. (2002). *Plasma Devices*. University of Malaya.

Ing, H., Djeffal, S., Clifford, T., Machrafi, R., & Noulty, R. (2007). Portable spectroscopic neutron probe. *Radiation Protection Dosimetry*, *126*(1–4), 238–243. https://doi.org/10.1093/rpd/ncm049

Jain, J., Moreno, J., Bora, B., & Soto, L. (2021). Influence of electrode geometry on X-ray emission, plasma inductance, voltage, and current derivative signals obtained from a plasma focus device. *Results in Physics*, *23*, 104016. https://doi.org/10.1016/j.rinp.2021.104016

Kenneth W. Struve, & Bruce L. Freeman. (2012). Dense Plasma Focus Neutron Generator for Active Interrogation. In *Sandia National Laboratories*.

Lang, R. F., Pienaar, J., Hogenbirk, E., Masson, D., Nolte, R., Zimbal, A., Röttger, S., Benabderrahmane, M. L., & Bruno, G. (2018). Characterization of a deuterium–deuterium plasma fusion neutron generator. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *879*, 31–38. https://doi.org/10.1016/j.nima.2017.10.001

Rahmani, F. (2016). Dose Calculation for Radiation Safety Assessment of Plasma Focus 2.5 kJ. *Journal of Fusion Energy*, *35*(2), 378–384. https://doi.org/10.1007/s10894-015-0043-0

Sato, T., Iwamoto, Y., Hashimoto, S., Ogawa, T., Furuta, T., Abe, S., Kai, T., Tsai, P.-E., Matsuda, N., Iwase, H., Shigyo, N., Sihver, L., & Niita, K. (2018). Features of Particle and Heavy Ion Transport code System (PHITS) version 3.02. *Journal of Nuclear Science and Technology*, *55*(6), 684–690. https://doi.org/10.1080/00223131.2017.1419890

Singh, A., Sing, L., Oun, T. T., & Heoh, S. S. (2022). Understanding Plasma Dynamics of Argentina Nano Focus Machine Using the Lee Code. *ASM Science Journal*, *17*, 1–7. https://doi.org/10.32802/asmscj.2022.955

Zanelli, D., López, E., Pavez, C., Pedreros, J., Jain, J., Avaria, G., Moreno, J., Bora, B., Davis, S., & Soto, L. (2018). Analysis of Deterioration in a Plasma Focus Device. *Journal of Physics: Conference Series*, *1043*, 012049. https://doi.org/10.1088/1742-6596/1043/1/012049

Zhukeshov, A. M., Moldabekov, Zh. M., & Ioffe, A. (2019). The plasma parameters and neutron yield at device of “Plasma focus.” *Physical Sciences and Technology*, *6*(1), 68–74. https://doi.org/10.26577/phst-2019-1-p2

Zin, M. F. M., Baijan, A. H., Damideh, V., Hashim, S. A., & Sabri, R. M. (2017). *Preliminary results of Malaysian nuclear agency plasma focus (MNA-PF) as a slow focus mode device for argon and deuterium filling gas in correlation with Lee model code*. 020005. https://doi.org/10.1063/1.4978818