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Even Mass Plutonium Effect On Plutonium Proliferation Evaluation For Delta Phase

Ismail Humolango[1], Muhamad Irfan[1], Imam Ghazali Yasmint[2], Sidik Permana[1,2,*], Sparisoma Viridi[1,2], Dwi Irwanto[1,2], & Abdul Waris[1,2]

[1]Graduate Program in Nuclear Engineering, Faculty of Mathematics and Natural Sciences, Bandung Institute of Technology Ganesha No. 10 Bandung, Indonesia
[2]Department of Physics, Faculty of Mathematics and Natural Sciences, Bandung Institute of Technology, Ganesha No. 10 Bandung, Indonesia
*Email: psidik@itb.ac.id

Abstract. Plutonium isotopes are one of the most popular sources used for making nuclear weapons. This is because the production of plutonium isotopes is quite a lot in nuclear reactors and has characteristics suitable for nuclear weapons. The resulting plutonium can exist in different phases depending on temperature. The delta phase is one of the phases most similar to metal, so it is easily forged and used as a nuclear weapon. The isotope of plutonium most often used as a nuclear weapon is the odd-numbered isotope because it has fissile capabilities, especially Pu-239, which is produced the most. One way to protect the isotope Pu-239 from being misused is to set up a plutonium isotope barrier. The regulation in question is adding (doping) and changing the composition of Pu-239 with an even-numbered isotope of plutonium. In this research, an analysis of the doping effect of even-numbered plutonium isotopes on Pu-239 will be carried out by focusing on the isotopic barrier parameters of plutonium, such as decay heat (DH), spontaneous fission neutron (SFN), bare critical mass (BCM) and Rossi-Alpha. These parameters were obtained by simulating a plutonium isotope fission event using a 4C MCNP with JENDL 3.3 library. Based on the simulation, the highest increase in decay heat was obtained by doping Pu-238. In the case of spontaneous fission of neutrons, it was found that Pu-238 doping gave high growth. Doping Pu-242 gives the highest increase in bare critical mass compared to other even-numbered isotopes. So for the decay heat and spontaneous fission neutron parameters, Pu-238 doping is the most effective doping. For bare critical mass and Rossi-alpha parameter, Pu-242 doping is the most effective.

Keywords: *Bare Critical Mass; Decay Heat; Isotopic Plutonium Barrier; Plutonium Doping, Rossi-Alpha; Spontaneous Fission Neutron.*

1 Introduction

Since the 1970s, plutonium conversion to explosive material has received significant interest. One of the most common sources used to create nuclear bombs is plutonium isotopes. Aside from the plutonium that already exists from nuclear bombs, the growing amount of plutonium from spent fuel increases the need for its security. Nuclear reactors produce a sizable amount of plutonium isotopes, which have properties that make them appropriate for nuclear weapons. Depending on the temperature, the resultant plutonium can exist in a variety of phases. One of the phases that resembles metal the most is the delta phase, which makes it simple to create and utilize as a nuclear weapon.

The odd-numbered isotope of plutonium, in particular Pu-239, which is the most produced, has the ability to fission, making it the isotope most frequently utilized in nuclear weapons. Early in the 1980s, a good summary of the efforts to make plutonium less desirable for explosives was published [1]. Establishing a plutonium isotope barrier is one technique to stop the isotope Pu-239 from being abused. A further ineffective method involved mixing gamma emitter nuclides with plutonium [2] and even burning plutonium in the form of an inert matrix fuel [3]. The easiest method, however, is to add more Pu-238 to the total amount of plutonium, either through modified fuel cycles [4], prolonged irradiation [5], admixing Np-237 [6], or admixing all minor actinides into uranium fuel [7]. Other methods, such as adding (doping), involve replacing Pu-239 with an even-numbered isotope of plutonium. Pu-238 can significantly influence the features of plutonium due to its intrinsic properties, which include a relatively high DH of 567 W/kg and an SFN rate of 2660 n/g/s. Following IAEA criteria, plutonium that contains 80% Pu-238 is not a proliferation threat [8]. Pu-240 and Pu-242, which have SFN of 1030 and 1720 n/g/s, respectively, and Pu-238 both share comparatively excellent qualities in terms of proliferation deterrent. As a result, the interaction between these even-mass-number plutonium isotopes will influence the features of plutonium that make it resistant to propagation.

In this research, an analysis of the doping effect of even-numbered plutonium isotopes on Pu-239 will be carried out by focusing on the isotopic barrier parameters of plutonium, such as decay heat (DH), spontaneous fission neutron (SFN) and bare critical mass (BCM). These parameters were obtained by simulating a plutonium isotope fission event using a 4C MCNP with JENDL 3.3 library.

2 Analysis and Methods

Isotopes barrier parameters including Rossi-alpha, bare critical mass, spontaneous fission neutron, decay heat, and material attractiveness all made reference to the Figure of Merit (FOM) idea [9] and the ATTR, as well as Kessler's denaturing plutonium theory [10] and Plutonium content, which the IAEA examination [11] and [12] both exclude. One of the most crucial elements to becoming a material that may be utilized as a parameter to protect isotope Pu-239 from being exploited is the isotopic composition of plutonium with an even mass. To get these characteristics, the 4C MCNP [13] and JENDL 3.3 library [14] were used to simulate a plutonium isotope fission event.

These features are used for determining proliferation resistance based explicitly on the plutonium composition since they are somewhat sensitive to the composition of plutonium isotopes. These crucial measurements include neutron spontaneous fission and decay heat. Even plutonium mass, such as Pu-238, Pu-240, and Pu-242, is utilized as a doping agent in the composition of Pu-239, a compound plutonium. Additionally, Based on the plutonium isotope composition as a function of time during reactor operation, these parameters were analyzed [15]. Equations (1) through (4) demonstrate those relationships between decay heat, spontaneous fission neutron, and elapsed time.

$$DH_i = DH_i^{ind} xrfPu_i \quad (1)$$

$$DH_{comp} = \sum_{i=1}^{n} DH_i \quad (2)$$

$$SFN_i = SFN_i^{ind} xrfPu_i \quad (3)$$

$$SFN_{comp} = \sum_{i=1}^{n} SFN \quad (4)$$

$$\alpha \equiv \frac{k_{eff}-1}{\tau_o} \quad (5)$$

Expression of DH_i defines a DH_i^{ind} is the decay heat value of each plutonium isotope for 100% pure isotopic plutonium, and $frPu_i$ is a fraction of the plutonium isotopic vector composition in the overall plutonium content as weight percentage. The DH comp parameter describes a plutonium compound's overall decay heat value, calculated using the contributions of all of its isotopes. The DH calculation also referred to in the Calculation of Spontaneous Fission Neutrons section, demonstrated that each SFN value of a specific plutonium isotope contributes to the SFN of the entire compound [15].

The ratio of super criticality (Keff-1), which essentially determines the energy yield of fissionable material to prompt neutron lifetime (τo), was demonstrated using the Rossi-alpha parameter as stated in equations (5) [16] and [9]. Based on the doping of Pu-239 with even-mass plutonium isotopes (Pu-238, Pu-240, and Pu-242), the Rossi-alpha value can be determined.

3 Results and Discussions

This section explains the relationship between doping addition and isotopic plutonium barrier parameters such as bare critical mass (BCM), Rossi-alpha, decay heat and spontaneous fission neutron (SFN). The discussion will be divided into two parts, the first covering BCM and Rossi-alpha and the second covering heat decay and SFN. The discussion is limited to plutonium in the delta phase.

3.1 Effect of Even Mass Plutonium Doping to BCM and Rossi-alpha

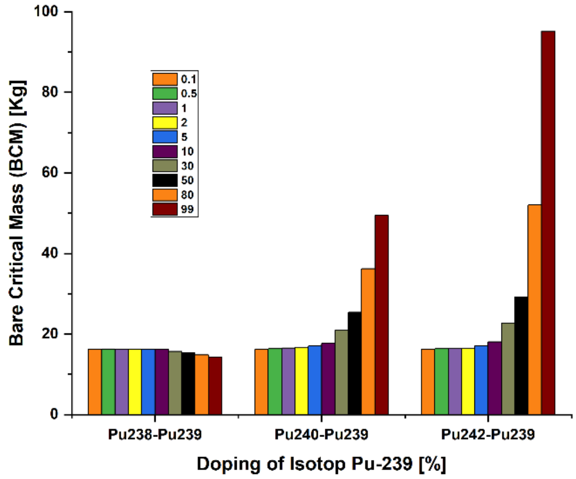

Figure 1 Bare Critical Mass (BCM) as a function of even mass plutonium doping composition.

Figure 1 shows the relationship between Bare Critical Mass (BCM) to the addition of doping. For the case of doping with Pu-238, the greater the addition of doping, the BCM will decrease. However, the decrease is not significant. This is because the BCM of Pu-238 is smaller than Pu-239, so a mixture of the two isotopes will give more or less the same BCM and decrease closer to BCM Pu-238 as the composition of Pu-238 increases. Meanwhile, for cases of doping with Pu-240 and Pu-242, the resulting BCM will be greater as the doping composition of Pu-240 and Pu-242 increases. This is also in line with the magnitude of the BCM of the isotopes Pu-240 and Pu-242.

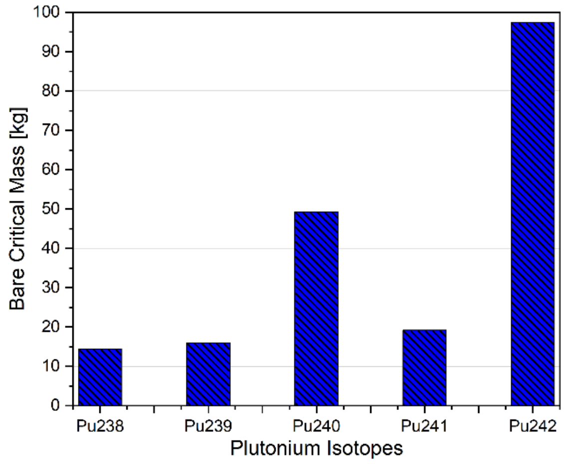

Figure 2 Bare Critical Mass (BCM) for each plutonium isotope.

The BCM for each plutonium isotope can be seen in Figure 2. Doping the isotope Pu-242 to Pu-239 will significantly increase BCM because it has the largest BCM value compared to other plutonium isotopes. The greater the BCM value, the more difficult it is for a material to be used as a nuclear weapon because it needs an enormous mass to become critical.

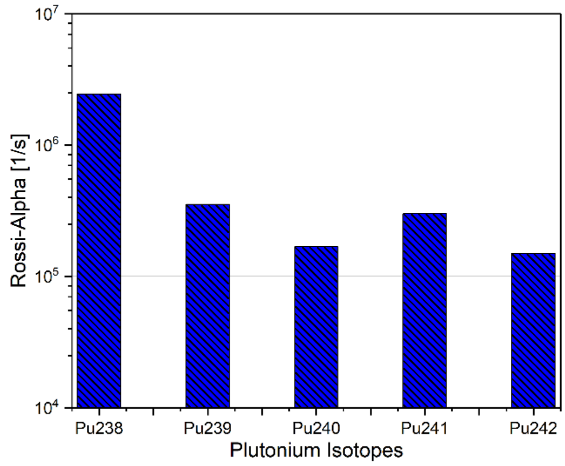

Figure 3 Rossi-alpha for each plutonium isotope.

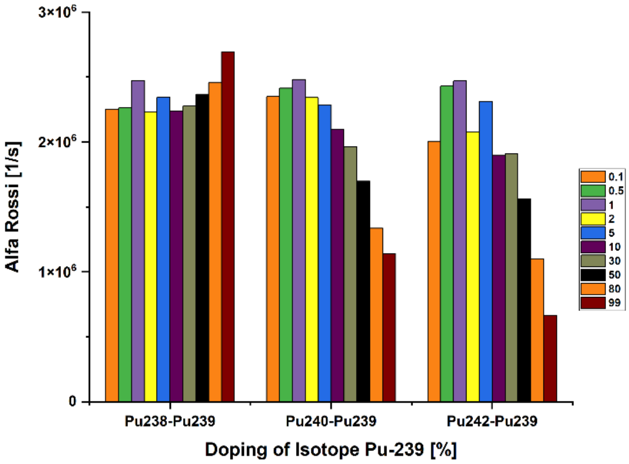

Figure 4 Rossi-alpha as a function of even mass plutonium doping composition.

Rossi-alpha is the ratio of super criticality to prompt neutron lifetime. Rossi-alpha value and BCM indicate the same thing for criticality. The difference is that criticality conditions will be more challenging to achieve with high BCM and low Rossi-alpha. The Rossi-alpha of each plutonium isotope follows Pu-238 > Pu-239 > Pu-241 > Pu-240 > Pu-242, as shown in Figure 3. This causes Rossi-alpha for doping Pu-238 to Pu-239 to increase following the increase in the composition of Pu-238. Likewise, Rossi-alpha mixed with Pu-240, or Pu-242 doping will decrease as the composition of Pu-240 or Pu-242 increases. The relationship between Rossi-alpha and the addition of doping can be seen in Figure 4. Thus, doping Pu-242 to Pu-239 will provide the most effective results for increasing the isotopic barrier parameters of BCM and Rossi-alpha.

3.2 Effect of Even Mass Plutonium Doping to Decay Heat and Spontaneous Fission Neutron (SFN)

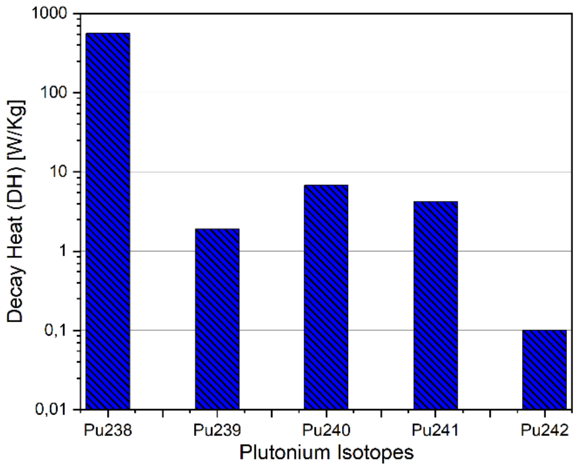

Figure 5 Decay heat for each plutonium isotope.

The results of the decay heat calculation from [17] are shown in Figure 5. The calculations found that the pure Pu-238 isotope had the highest decay heat compared to other plutonium isotopes in the order Pu-238 > Pu-240 > Pu-242 > Pu-239 > Pu-242. The higher the decay heat value, the higher the isotopic barrier parameter. This is because the high decay heat value requires a high heat-resistant handler/material, which will complicate its implementation in manufacturing nuclear weapons.

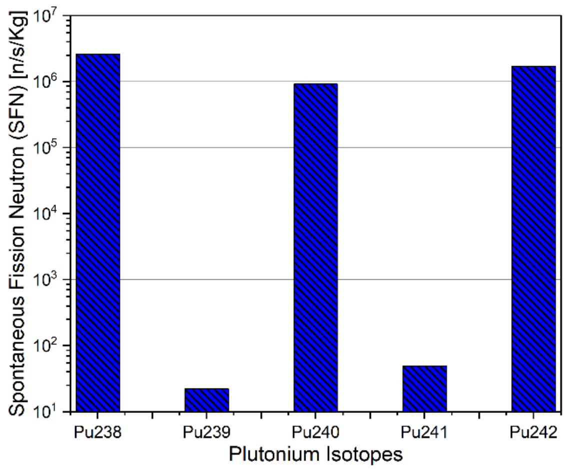

Figure 6 Spontaneous Fission Neutron (SFN) for each plutonium isotope.

Figure 6 shows the calculation results of spontaneous fission neutron (SFN) from [17], which is the intensity of spontaneous neutron production in the material. The higher the SFN value, the more neutrons are produced, which causes the material to become more unstable and challenging to control, so the isotopic barrier parameter is also higher. The SFN obtained are very large and quite similar for the even mass plutonium but very small for the odd mass plutonium.

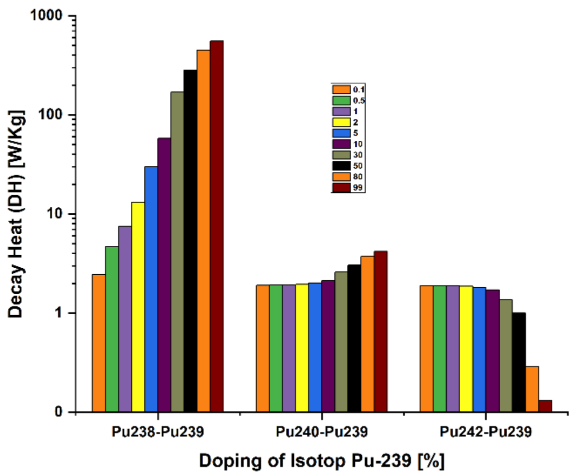

Figure 7 Decay heat as a function of even mass plutonium doping composition.

Figure 7 indicates the relationship of doping to the isotope Pu-239. The decay heat value of the Pu-239 isotope mixture increases with the Pu-238 or Pu-240 isotope composition but will decrease for the Pu-242 isotope. This is because the decay heat values of Pu-239 and Pu-240 are more significant than the decay heat values of Pu-239, and Pu-242 is the smallest among other plutonium isotopes.

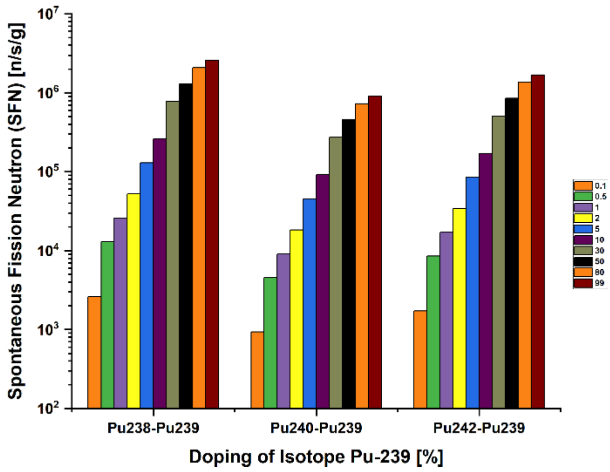

Figure 8 Spontaneous Fission Neutron (SFN) as a function of even mass plutonium doping composition.

Based on Figure 8, it was also found that the doping of the even-numbered isotope of plutonium against the isotope Pu-239 produced a somewhat similar SFN. The larger the isotope composition with an even number, the higher the SFN value in Pu-238-Pu-239 > Pu-242-Pu-239 > Pu-240-Pu-239. Thus, doping with the isotope Pu-238 to Pu-239 gives the most effective results for increasing the isotopic barrier parameter decay heat and is quite good (second position) for SFN.

4 Conclusion

The primary metrics for assessing proliferation survival based on plutonium composition are the barrier parameters for isotopic plutonium, such as decay heat, spontaneous fission neutrons, bare critical mass, and Rossi-alpha. To prevent the misuse of plutonium, especially for Pu-239, which has the highest fissile capacity, by adding or changing the composition of Pu-239 with even mass plutonium (Pu-238, Pu-240, and Pu-242).

The highest increase in decay heat was obtained by doping Pu-238. In the case of spontaneous fission of neutrons, it was found that Pu-238 doping gave high growth. Doping Pu-242 gives the highest increase in bare critical mass compared to other even-numbered isotopes. Pu-238 doping is therefore the most efficient doping for the neutron parameters of spontaneous fission and decay. For bare critical mass and Rossi-alpha parameter, Pu-242 doping is the most effective.

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