

INTISARI

SIMULASI DESAIN *BEAM SHAPING ASSEMBLY* (BSA) *DOUBLE LAYER* DAN OPTIMASINYA MENGGUNAKAN ALGORITMA GENETIKA (AG) GUNA MENGHASILKAN NEUTRON EPITERMAL UNTUK *BORON NEUTRON CAPTURE THERAPY* (BNCT)

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Telah dilakukan pengembangan desain *Beam Shaping Assembly* (BSA) guna memoderasi neutron cepat menjadi neutron epitermal yang sesuai standar International Atomic Energy Agency (IAEA) sehingga bisa digunakan untuk *Boron Neutron Capture Therapy* (BNCT). Model BSA didesain menggunakan *software Monte Carlo N-Particle X* (MCNPX) dalam bentuk *double layer* yaitu masing-masing komponen BSA yang terdiri dari moderator, reflektor, kolimator dan filter dibuat menggunakan dua material. Optimasi desain *Double Layer Beam Shaping Assembly* (DLBSA) dilakukan menggunakan metode algoritma genetika (AG). Implementasi optimasi DLBSA menggunakan AG dilakukan melalui mekanisme representasi kromosom, evaluasi fungsi *fitness*, *crossover*, mutasi dan seleksi. Hasil desain terbaik dari MCNPX dan optimasi AG diverifikasi menggunakan *software* pembandingan yaitu *Particle and Heavy Ion Transport code System* (PHITS). Indikator keberhasilan desain tersebut adalah apabila kedua *software* menghasilkan lima parameter berkas neutron epitermal sesuai standar IAEA. Lima parameter berkas neutron epitermal yang disarankan IAEA adalah fluks neutron epitermal $\geq 1,0 \times 10^9$ n/(cm².s), rasio fluks neutron epitermal (φ_{epi}) terhadap fluks neutron termal (φ_{th}) dan fluks neutron cepat (φ_{fast}) harus lebih besar dari 100 dan 20, dan rasio laju dosis serap neutron cepat (\dot{D}_f) dan laju dosis gamma (\dot{D}_γ) terhadap fluks neutron epitermal (φ_{epi}) masing-masing $\leq 2,0 \times 10^{-13}$ Gy.cm².

Prediksi awal dengan metode bertahap terhadap pengujian DLBSA menggunakan delapan kombinasi material moderator, empat kombinasi material reflektor, satu kombinasi material kolimator dan empat kombinasi material filter diperoleh konfigurasi optimum yang mampu menghasilkan berkas neutron epitermal sesuai standar IAEA. Konfigurasi optimum diperoleh dengan mengkombinasikan Al dan BiF₃ sebagai moderator, Pb dan C sebagai

reflektor, Ni dan *Borated polyethylen* sebagai kolimator serta Fe dan Cd sebagai filter neutron cepat dan neutron termal.

Pengembangan metode optimasi menggunakan algoritma genetika (AG) sampai generasi ke-30 diperoleh delapan konfigurasi yang mampu menghasilkan berkas neutron epitermal sesuai standar IAEA. Delapan konfigurasi terbaik didapatkan dengan mengkombinasikan: (1) Al dengan salah satu material CaF_2 , BiF_3 atau PbF_2 sebagai moderator, (2) Pb dengan salah satu material Pb, Ni, atau Bi sebagai reflektor, (3) Ni dengan material FeC, atau C sebagai kolimator, (4) (FeC + LiF) sebagai filter neutron cepat, Cd atau B_4C sebagai filter neutron termal, serta Pb sebagai *shielding* gamma.

Karakteristik output neutron epitermal delapan konfigurasi DLBSA pada generasi ke-30 telah menghasilkan berkas neutron epitermal sesuai persyaratan terapi BNCT. Desain DLBSA pada generasi ke-30 menghasilkan berkas neutron terbaik dengan nilai fluks neutron epitermal sebesar $1,29 \times 10^9$ n/(cm².s), rasio fluks neutron epitermal (φ_{epi}) terhadap fluks neutron termal (φ_{th}) dan fluks neutron cepat (φ_{fast}) sebesar 705 dan 56, dan rasio laju dosis serap neutron cepat \dot{D}_f dan dosis gamma (\dot{D}_γ) terhadap fluks neutron epitermal (φ_{epi}) masing-masing $1,51 \times 10^{-13}$ Gy.cm² dan $0,25 \times 10^{-13}$ Gy.cm².

Verifikasi terhadap delapan konfigurasi model DLBSA yang optimum menggunakan pemrograman PHITS menunjukkan bahwa berkas neutron epitermal yang dihasilkan DLBSA juga telah memenuhi standar IAEA. Hasil uji berkas neutron epitermal yang dihasilkan oleh DLBSA dan diiradiasikan terhadap phantom air menunjukkan bahwa berkas neutron epitermal berubah menjadi neutron termal ketika masuk ke dalam phantom. Neutron termal tersebut mampu menjangkau kedalaman phantom 2-8 cm. Oleh karena itu berkas neutron epitermal yang dihasilkan DLBSA dapat dimanfaatkan untuk terapi kanker *Boron Neutron Capture Therapy* (BNCT) dengan posisi lebih dalam.

Kata Kunci: Algoritma genetika, *beam shaping assembly*, BNCT, neutron epitermal, standar IAEA

ABSTRACT

SIMULATION OF DOUBLE LAYER BEAM SHAPING ASSEMBLY (DLBSA) DESIGN AND ITS OPTIMIZATION USING GENETIC ALGORITHM (GA) TO PRODUCE EPITHERMAL NEUTRON FOR BORON NEUTRON CAPTURE THERAPY (BNCT)

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A design of Beam Shaping Assembly (BSA) has been developed to moderate fast neutrons into epithermal neutrons that meet the International Atomic Energy Agency (IAEA) standard for Boron Neutron Capture Therapy (BNCT) purposes. The model of BSA was designed using the Monte Carlo N-Particle X (MCNPX) software in form of a double layer, where each component of the BSA, consisting of moderator, reflector, collimator, and filter were made of two materials. Optimization of the Double Layer Beam Shaping Assembly (DLBSA) design is accomplished using the genetic algorithm (GA) method. In implementation, the optimization of DLBSA using the GA was carried out through mechanism of chromosome representation, evaluation of fitness function, crossover, mutation, and selection. The best design resulted from the MCNPX and optimization by GA was verified using a comparer software, i.e. the Particle and Heavy Ion Transport code System (PHITS). The indication for the success of the design is when both softwares yield five parameters that meet the IAEA standard. The five parameters of epithermal neutron beams prescribed by the IAEA are epithermal neutron flux $\geq 1,0 \times 10^9$ n/(cm².s), ratio of epithermal neutron ($\{_{epi}\}$) to thermal neutron ($\{_{th}\}$) and fast neutron ($\{_{fast}\}$) flux higher than 100 and 20, and ratio of fast neutron absorption dose rate (\dot{D}_f) and gamma dose rate (\dot{D}_γ) to epithermal neutron ($\{_{epi}\}$) of $2,0 \times 10^{-13}$ Gy.cm² each.

Initial prediction by gradual method on DLSBA test using eight combinations of moderator materials, four combination of reflector materials, one combination of collimator materials, and four combination of filter materials yields an optimal configuration able to produce epithermal neutron beams that meet the IAEA standard. The optimal configuration is obtained by combining Al and BiF₃ as the moderator, Pb and C as the reflector, Ni and

Borated polyethylene as the collimator, and Fe and Cd as the filter for fast neutrons and thermal neutrons.

It is obtained from the development of optimization method using the genetic algorithm (GA) method down to the 30th generation that eight configurations are able to produce epithermal neutron beams that meet the IAEA standard. Such best configuration is attained by combining: (1) Al and either CaF₂, BiF₃ or PbF₂ material as moderator, (2) Pb and either one of Pb, Ni, or Bi material as reflector, (3) Ni and material FeC, or C material as collimator, (4) (FeC + LiF) as fast neutron filter, Cd or B₄C as thermal neutron filter, and Pb as gamma shielding.

The epithermal neutron output characteristics of eight DLBSA configurations in the 30th generation have produced epithermal neutron beams according to BNCT therapy. The DLBSA design in the 30th generation produced the best neutron beam with epithermal neutron flux values of $1.29 \times 10^9 \text{ n / (cm}^2 \cdot \text{s)}$, the ratio of epithermal neutron flux (φ_{epi}) to thermal neutron flux (φ_{th}) and fast neutron flux (φ_{fast}) 705 and 56, and the dose rate ratio fast neutron absorption \dot{D}_f and gamma dose (\dot{D}_γ) of epithermal neutron flux (φ_{epi}) are $1.51 \times 10^{-13} \text{ Gy} \cdot \text{cm}^2$ and $0.25 \times 10^{-13} \text{ Gy} \cdot \text{cm}^2$, respectively.

Verification against eight configurations of optimal DLSBA model using PHITS programming reveals that the epithermal neutron beams produced by the DLSBA also conform the IAEA standard. The testing of epithermal neutron beams produced by the DLSBA and irradiated on a water phantom shows that epithermal neutron beams transform into thermal neutron upon entering the phantom. The thermal neutron can penetrate the phantom up to 2-8 cm deep. Therefore, the epithermal neutron beams produced by the DLSBA can be utilized for Boron Neutron Capture Therapy (BNCT) therapies of deeper located cancers.

Keywords: Genetic Algorithm, beam shaping assembly, BNCT, epithermal neutron, IAEA standard