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Proposed Innovative Correlations for some Nuclear and Radiological Fields using Theorem of S. El-Mongy

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Abstract

Thinking and thought are divine urge in the Great Quran. The published S. El-Mongy theorem ($L= e\pi r s^A$) correlates eπ with radius r of circular and spherical geometries by a factor s^A (θ/10ϕ) to be used for calculations of arc length and astronomical distance. In this article, Sayed's formula was used to produce correlations with the well-established laws and formulas of different nuclear and radiological fields. The formula was directed to be correlated with half-life time, activity, flux, reaction rate, reactor power, mean free path, photon fluence rate, radiation dose rate and half value thickness equations. It was also oriented to calculate fuel rods circumstances of different reactor types; PWR, BWR, VVER1200 and Candu-6. The produced correlations of eπ and s^A with the above mentioned topics are given with simplified reduced forms, limitation and some comparative calculations between old and the proposed innovative formulas. New formulas for sphere volume and surface area and cylinder are also given based on eπ term.

Keywords: Sayed`s formula, eπ term, different nuclear and radiological laws, innovative proposed formulas.

I. Introduction

Based on Sayed`s theorem (1), different nuclear and radiological field laws and equations were correlated and formulated. It may be exceptional and remarkable job to correlate the well-known published nuclear equations with our formula to be integrated with the eπ term. The science is mainly based on observations, outstanding and may be abnormal ideas. Nuclear sciences began from basic ideas and laws to be as it is in the modern developed level (2,3). The long way of scientific history, challenges and development was based on integration of the human ideas, axioms, discoveries and inventions (3,4).

II. Correlation of Sayed`s Formula with some Nuclear and Radiological Fields

In this part, Sayed`s formula was used to calculate the fuel rods circumstances for different reactor types. The formula is expressed as follows (1):

$$\mathbf{L = e\,\pi\, r\, s^A} \qquad (1)$$

Where s^A is Sayed constant (ϴ/10ϕ), e is Euler constant, π is Archimedes number, L is arc length and r is the radius of circular or spherical geometry.

II.1) Correlation with Half-Life Time Calculation;

The half-life time is $T_{1/2} = 0.69315/\lambda$ (5,6,7,8,9), where λ is the decay constant (sec^{-1}). As a matter of fact the nuclides decay and emit radiation in isotropic manner. Based on that, this formula can be given in correlation with eπ term. In this case the half life time can be expressed as:

$$\mathbf{T_{1/2} = e\,\pi\,/12.32\,\lambda} \qquad (2)$$

Where, ln2=0.69315 = **(eπ/12.32).** This correlation was validated and compared with the major $T_{1/2}$ equation for some isotopes ($T_{1/2}$ from seconds to >10^9 year). The simple comparative results are given in Table 1.

Table 1: Correlation of Half-life Time with eπ for different Isotopes

Isotope	$T_{1/2} = 0.693/\lambda$	$T_{1/2} = e\pi/12.32\lambda$	% difference
^{22}O	2.25 sec.	2.251	0.044
^{259}Nobelium	58 min.	58.02	0.034

^{192}Ir	74 d.	74.02	0.027
^{60}Co	5.3 yr.	5.30	-----
^{137}Cs	30.17 yr.	30.176	0.021
^{239}Pu	24100 yr.	24105.53	0.023
^{238}U	$4.5x10^9$ yr.	$4.50x10^9$	-----

II.2) Correlation with Activity Calculation

The activity (A) is simply expressed as in the following expression (5,6,7,8,9):

$$A = N\lambda \quad (3)$$

It can be correlated with the term eπ by substituting equation 2 in 3 as;

$$\mathbf{A = N\, e\, \pi /12.32\, T_{1/2}} \quad (4)$$

Where, the term (e π /12.32) equal to ln2 as mentioned above.

II.3) Correlation with Sphere Surface Area and Volume:

The radiation is emitted isotropically in every direction. So, correlation of volume and surface area of the sphere of radius (r) using Sayed formula (1) can be expressed as:

$$\textbf{Sphere volume} = 4/3\,\pi r^3 = 0.4905\, e\pi r^3 \quad (5)$$

$$\textbf{Sphere surface area} = 4\,\pi r^2 = 1.471518\, e\pi r^2 \quad (6)$$

Comparison of the calculations carried out by the abovementioned formula is given in Table 2.

Table 2: Correlation of eπ with sphere volume formula

Radius Volume	Old formula; ($4/3\pi r^3$)	New formula; ($0.49\, e\pi\, r^3$)	% Diff.
0.5 cm	0.52359833 cm^3	0.52359166	0.00127
1 cm	4.1887866 cm^3	4.188784	$6.2x10^{-5}$
5 cm	523.59833 cm^3	523.59166	0.00127
5 m	523.59833 m^3	523.59166	0.00127
10 m	4188.7866 m^3	4188.73328	0.00127
1000 km	4188786666.666 km^3	4188733280.58	0.00127
10^{26} km (~10^{13} ly)	4.1887866 x 10^{78} km^3	4.18873328 x 10^{78}	0.00127

The results of surface area calculations for the sphere using the new correlation are given in Table 3:

Table 3: Correlation of eπ with sphere surface area formula

Surface area Radius	Old formula; ($4\pi r^2$)	New formula; ($1.4715\, e\pi r^2$)	% Diff.
0.5 cm	3.14159	3.14154996	0.00127
1 cm	12.56636 cm^2	12.5661998	0.00127
5 cm	314.159 cm^2	314.154996	0.00127
5 m (500 cm)	314.159 m^2	314.154996	0.00127
10 m	1256.636 m^2	1256.6199	0.00127

1000 km	12566360 km^2	12566199.84	0.00127
10^{26} km (~ 10^{13} ly)	1.256636 x 10^{53} km^2	1.2566199 x 10^{53}	0.00128

It can be observed the negligible difference between the well-known formulas and the correlated new ones.

In case of cylindrical geometry of height (h), the volume can be correlated as follow;

Cylinder volume = $\pi r^2 h = 0.368\, e\pi r^2 h$ (7)

II.3) Correlation with Inverse Square Law Formula:

The relation between source intensity and distance is expressed as the inverse square law (5,6,7,8). The intensity (I) at surface of a sphere is proportional to the source strength (I_0) as follow.

$I = I_o / 4\, \pi r^2$ (8)

Correlating the value of r of equation 1 in equation 8, one gets:

$I = I_0\, e^2\, \pi^2\, \theta^2 / 4x100\, \pi\phi^2\, L^2$ (9)

The equation 9 can be reduced for $\theta = 360^0$ to be:

$I = 3.14159\, I_o/ L^2$ or (10)

$I = \pi I_o/ L^2$ (11)

Also, by using equation 6 for sphere surface area, the radiation intensity can be given as;

$I = I_o / 1.471518\, e\pi\, r^2$ (12)

II.4) Correlation with Radiation Dose Rate Calculation:

The radiation dose rate (D) at any distance r was also correlated and formulated. Using the well-known dose rate equation (5,6,7,8):

$D = \Gamma A / r^2$ (13)

Where, Γ is the gamma constant, A is source activity and r is the distance from unshielded source. In case of a circle with radius equal to r, the radiation dose rate at any point at the circle boundary can be correlated with equation 1 in 13 to be:

$10\phi\, L / e\, \pi\, \theta = \Gamma^2\, A^2 / D^2$ (14)

$D = (\Gamma\, A/L^2)\, (e^2\, \pi^2\, \theta^2 / 100\, \phi^2)$ (15)

For $\theta = 360^0$, this equation can be reduced to be:

$D = 5.343\, (\Gamma\, A/L^2)$ (16)

II.5) Correlation with Photon Fluence rate:

The photon fluence rate (Φ_P) from a point source is expressed by the formula;

$\Phi_P = A\, I_Y/ 4\pi\, r^2$ (17)

Where, Φ_P in 'Y /cm^2.hr, A is the source activity (decay/hr) , I_Y is the photon yield ('Y/decay) and r is the distance from a point source (cm). The correlation of equation17 with formula number 1, the fluence rate can be;

$\Phi_P = A\, I_Y / 4\pi\, r^2 = A\, I_Y\, e^2 \pi\theta^2/ 400\, \phi^2\, L^2$ (18)

In a reduced form for $\theta=360^0$, the fluence rate is;

$\Phi_P = 3.14\, A\, I_Y /L^2 = A\, I_Y\, \pi/L^2$ (19)

By using equation 6, the correlation is;

$\Phi_P = A\ I_Y / 1.47\ e\pi r^2$ (20)

II.6) Correlation with Mean Free Path of Photons and Neutrons:

The mean free path (mfp) is the average distance a photon travels before an interaction takes place. It is the reciprocal of the linear absorption coefficient μ The mfp of photon can be expressed as 1/μ, where μ is the linear attenuation coefficient (cm^{-1}). The half value thickness is expressed as (5,6,7,8,9);

H.V.T = ln2/ μ = 0.693/ μ (21)

This equation can also be correlated with the term eπ to produce the following one;

(mfp) = 12.32 H.V.T/ eπ (22)

It can also be reduced to be;

mfp = 1.44267 H.V.T or H.V.T. = 0.693 mfp (23)

The H.V.T can also be correlated as;

H.V.T = eπ (mfp) / 12.32 (24)

For **neutrons**, the mean free path (mfp) is given by the inverse of the macroscopic cross section (**1/Σ**) for a given material, which has the dimensions of a distance, does have an easily visualized meaning. For example, the quantity **1/Σa** equals the average distance that a neutron will travel before being absorbed by the material, and is known as the absorption mean-free-path, (**mfp**). Similarly, the inverse of the macroscopic scattering cross-section, **1/Σs**, is equal to the average distance traveled by a neutron between scattering collisions. The macroscopic cross-section equal **Σ = Nσ**. Where, N is the number of atoms per cm^3 and σ is the microscopic cross section (9). The mean free path to absorption is mfp = Σ^{-1}. The flux (ϕ) is the total neutron track length laid down in one second in one cm^3, so dividing flux by the length of track required (on average) for one absorption, we get the total number of absorptions that is (9 new):

R_a = total track length (per s per cm)/ neutron mean free path to absorption (25)

$R_a = \phi/mfp$ or $mfp = \phi/R_a$ or $R_a = \phi\ \Sigma_a$ (26)

With ϕ in $cm^{-2}\ s^{-1}$ and Σ_a in cm^{-1}, R_a has units $cm^{-3}\ s^{-1}$.

II.7) Correlation with Reaction Rate Calculation:

The reaction rate, R, is the number of reactions per second per cubic centimeter of material. To calculate the reaction rate (RR) of mono-energetic neutrons with gas atoms in a spherical ion chamber for example, it can be given as follow (5,7,8,9,10,11):

$RR = \sigma\ n\ \phi / 4\ \pi r^2$ (27)

Where, σ is the microscopic cross section, n number of atoms and ϕ is the flux (n/cm^2.sec.).

From the formula 1 and by substitution in equation 27,

$RR = \sigma\ n\ \phi / 4\ \pi r^2 = \sigma\ n\ \phi / 4\ \pi\ (10L\ \phi_a / e\ \pi\ \Theta)^2$ (28)

$RR = \sigma\ n\ \phi\ e^2\ \pi^2\ \Theta^2 / 400\ \pi\ L^2\ \phi_a^2$ (29)

$RR = 3.14159\ \sigma\ n\ \phi / L^2$ (30)

$RR = \pi\ \sigma\ n\ \phi / L^2$ (31)

Using equation 6 (for sphere surface area), the reaction rate can also be expressed as;

$RR = \sigma\ n\ \phi / 1.471518\ e\pi\ r^2$ (32)

II.8) Correlation with Flux Calculation of Neutrons Sources:

In case of unshielded neutron source (e.g. ^{226}Ra-^{9}Be), it emits fast neutrons distributed isotropically over spherical geometry, its flux can be given by the following equation (5,9,10):

Flux = No. of neutron produced per sec. (Pn) / surface area

Flux = $P_n/4\ \pi r^2$ (33)

By substituting value of r in Sayed formula 1, it produces;

Flux = $P_n\ e^2\pi^2\ \theta^2/\ 400\ L^2\ \phi^2$ (34)

For $\theta=360^0$, the flux due to the neutron source can be simply expressed as;

Flux = $\pi P_n/L^2$ (35)

Using equation 6, the flux can also be correlated as:

Flux = $P_n/1.471518\ e\pi\ r^2$ (36)

II.9) Correlation with Reactor Power formula:

The power released in a reactor can be calculated by multiplying the reaction rate by the volume of the reactor results in the total fission rate for the entire reactor. By dividing the number of fissions per watt-sec., results in the power released by fission in the reactor in units of watts (9,10,11,12,13,14,15). This relationship is mathematically shown in the next equation number 37

P = $\phi_{th}\ \sum_f V\ /\ 3.12\text{x}10^{10}$ fission/watt. sec. (37)

Where, P is the power (watts); each watt of power requires about 3.1 × 10^{10} fissions/s). ϕ_{th} is the thermal neutron flux (neutrons/cm^2-sec), $\sum_f$ is the macroscopic cross section for fission (cm^{-1}) and V is the volume of core (cm^3). By correlating this equation with Sayed formula for volume (spherical core), it produces:

P = $\phi_{th}\ \sum_f\ (4000\pi\ \phi^3\ L^3\ /\ e^3\pi^3\Theta^3\ \text{x}\ 3.12\text{x}10^{10})$ (38)

It can be reduced to be;

P = $5.567\ \text{x}\ 10^{-13}\ \sum_f\ \phi_{th}\ L^3$ (39)

The reactor power can also be expressed by substituting the volume of sphere in the formula number 5 in equation 37 to produce;

P = $\phi_{th}\ \sum_f\ (e\pi\ r^3F)\ /\ 3.12\text{x}10^{10}$ fission/watt. sec. (40)

Where, F is 0.4905059. In a reduced form, the reactor power in watt sec. is expressed as;

P = $0.15\text{x}\ 10^{-10}\ \sum_f\ \phi_{th}\ e\pi\ r^3$ (41)

For cylindrical core, the correlation will be;

P = $\sum_f\ \phi_{th}\ h\ (100\pi\ \phi^2\ L^2\ /\ e^2\pi^2\Theta^2\ \text{x}\ 3.12\text{x}10^{10})$ (42)

The reduced form can be given as;

P = $2.567\ \text{x}\ 10^{-12}\ \sum_f\ \phi_{th}\ L^2\ h$ (43)

Using equation 7 for cylindrical geometry, the power can also be correlated as:

P = $0.11795\text{x}10^{-10}\ e\pi r^2h\ \phi_{th}\ \sum_f$ (44)

II.10) Correlation with Reactor Fuels Rods Dimensions/Circumstances:

The characteristics of the fuel rods for different reactor types (e.g. Pressurized water reactor, Boiling water reactor, Candu reactor and Russian VVER reactor) are given in Table 4 (9,10,11,12,13,15,16,17,18).

Table 4: Fuel Rods Characteristics of different Reactor types

Parameter / Reactor type	PWR 17x17	BWR 8x8	VVER1200	Candu-6
Clad diameter	0.94 cm	1.23 cm	0.91 cm	0.654 cm
Fuel pellet diameter	0.8	1.04	0.76	0.6122

Clad thickness	0.061	0.0813	0.069	0.0418
Gap thickness	0.084	0.0112	0.081	----
Pellet length	1.14	1.14	1.1	1-1.3

This formula as given in equation 1 can be reduced for a circle of central angle $\Theta = 360^0$ to be:

$L = 6.28319\ r$ or $r = L/0.15915$ (45)

Where L is the circumstance of fuel rod; Clad, pellet and gap, and r is the fuel rod radius. The results of different reactors fuel rod type calculations are given in the following Table 5:

Table 5: Result of Fuel Rods Parameters Calculation for different Reactor types

Parameter / Reactor type	**PWR 17x17**	**BWR 8x8**	**VVER1200**	**Candu-6**
L_{Clad}	5.9032	7.7244	2.8574	4.10712
$L_{fuel\ pellet}$	5.0238	6.5312	2.3864	3.8446
L_{Gap}	2.4806	3.41318	0.2543	----
$L_{clad} / L_{fuel\ pellet}$	1.175	1.18269	1.197	1.06827
$L_{Clad} - L_{fuel\ pellet}$	0.8792	1.1932	0.471	0.2625

The calculated values shown in table5 are identical to the fuel pellet, clad and gap circumstances as calculated by using the old circular circumstance formula; $2\pi r \theta/360$ (1).

It can be observed that the proposed innovative correlated formulas cover different topics and axes in the nuclear and radiological fields.

Conclusion

Based on S. El-Mongy theorem and formula, the proposed correlations of the term $e\pi$ and s^A with different well established radiological and nuclear laws and formulas (e.g. half-life time, activity, flux, reaction rate, reactor power, mean free path, photon fluence rate, radiation dose rate and half value thickness) were mathematically performed in this article. The correlated formulas may be competitive and could be used as alternatives according to the data available and the unknown parameters to be calculated. The sphere volume and surface area were also correlated with $e\pi$.

Conflicts of interest

There are no any conflicts of interest with anyone.

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