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ORIGINAL RESEARCH

Advanced Power Conversion Efficiency in Inventive Plasma for Hybrid Toroidal Reactor

Aybaba Hançerlioğullari · Mesut Cini · Murat Güdal

Abstract Apex hybrid reactor has a good potential to utilize uranium and thorium fuels in the future. This toroidal reactor is a type of system that facilitates the occurrence of the nuclear fusion and fission events together. The most important feature of hybrid reactor is that the first wall surrounding the plasma is liquid. The advantages of utilizing a liquid wall are high power density capacity good power transformation productivity, the magnitude of the reactor's operational duration, low failure percentage, short maintenance time and the inclusion of the system's simple technology and material. The analysis has been made using the MCNP Monte Carlo code and ENDF/B–V–VI nuclear data. Around the fusion chamber, molten salts Flibe (LI_2BeF_4), lead–lithium (PbLi), Li–Sn, thin-lityum ($Li_{20}Sn_{80}$) have used as cooling materials. APEX reactor has modeled in the torus form by adding nuclear materials of low significance in the specified percentages between 0 and 12 % to the molten salts. In this study, the neutronic performance of the APEX fusion reactor using various molten salts has been investigated. The nuclear parameters of Apex reactor has been searched for Flibe (LI_2BeF_4) and Li–Sn, for blanket layers. In case of usage of the Flibe (LI_2BeF_4), PbLi, and thin-lityum ($Li_{20}Sn_{80}$) salt solutions at APEX toroidal reactors, fissile material production per source neutron, tritium production speed, total fission rate, energy reproduction factor has been calculated, the results obtained for both salt solutions are compared.

Keywords Apex · Mcnp · Hybrid · Blanket · Toroid

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Abbreviations

R	Major radius of toroid
r	(b − R)minor radius of toroid
T_6	Tritium breeding rate obtained from reaction ^{6}li(n,α)T
T_7	Tritium breeding rate obtained from Reaction ^{7}Li(n,α,n′)T
TBR: $T_6 + T_7$	Tritium breeding ratio
MHD	Magneto hydrodynamic
M	The energy multiplication factor
Δc	Atomic density change
$\int B \cdot dS = \mu_0 iN$	Amper Laws
Φ	Neutron flux

Introduction

APEX toroidal hybrid reactors are reactors that the fusion and fission reactions are realized together. This reactor is a new fusion reactor design that uses a liquid wall between the fusion plasma and solid first wall for either tritium breeding or energy transfer. In these kind of reactors, the combustion chamber is covered by low caliber passive nuclear materials such as (U^{238} and Th^{232}). The low caliber nuclear materials U^{238} and Th^{232} may react with fast neutrons. The fast neutrons that these materials require for reaction may be met by a fusion reaction provided by high energy 14 MeV neutrons similar to the hydrogen combustion that occurs in plasma. Very valuable nuclear fuels like Pu^{239} and U^{233} are maintained as a result of the reaction of U^{238} and Th^{232} with fast neutrons. Thus, very high quality fissile fuel may be obtained in an environment which is rich in energetic neutrons. The neutrons that are radiated as a result of the fusion reactions that occur at the plasma are captured at the blanket by uranium an thorium and the production of fissile fuel is provided. It is not possible to combust U^{238} in most reactors because the fusion impact incision is very low and the activation energy is too high. Th^{232} also is not an appropriate material for combustion.

Nevertheless, the knowledge that the known reserves of Th^{232} in the world is three times the reserve of Uranium, is alone sufficient to emphasis the importance of this material which has no value as a nuclear fuel, to be converted into a very valuable nuclear fuel by processing at a hybrid nuclear reactor. While a portion of this obtained fuel is used as fuel at the reactor, a large amount is transferred out of the reactor with appropriate methods and used as fuel at the thermal reactors While hybrid reactors enable an important portion of the constitution and continuity of the conventional nuclear reactors where they are used, because of the fact that these reactors work under critical, high security factor in the working conditions and a more flexible fuel renewal conditions are in application. Again, at these reactors, the combustion of the wastes of the nuclear reactor with a high efficiency or transformation to highly valuable fissile materials like Am^{242} and Cm^{245} is provided. A hybrid reactor, produces 30 times as much nuclear fuel per unit clear energy it exposes compared to the fast reactors. We can say that the nuclear fuels that a type hybrid DD reactor working with 1000 MW power can meet the requirements of about 160 nuclear plants working with the same power and also may produce fuel for 6 separate fusion reactors of various types Besides all these, the main disadvantage of a hybrid reactor is the fact that it contains two complex technologies which we name as fusion neutron source and complex fissile blanket within its structure [1].

Toroidal Design for Fusion Plasma

The main concept of APEX hybrid toroidal reactor systems has been used flowing liquids as the inner surface of the vacuum chamber that directly faces the plasma. Chamber technology refers to the pieces in reactor toroidal systems that directly plasma [2]. A toroidal chamber where a plasma is magnetically trapped. It is used in nuclear fusion research. The systems made of advance complex design of magnetic fields that restrict the plasma of reactive charged particles in a hallow. The most extensively investigated toroidal confinement concept is the tokamak. Magnetic constrict of plasmas is the most developed come up to controlled fusion.

The most of the problem of fusion has been success of magnetic field system that actively confine the plasma.

A successful systems must up three states: (1) the plasma have to be a time-independent equilibrium, (2) the equillibrum must be macroscopically stable, (3) the fugitive of plasma energy to the boundary wall have to minor. we can calculate the magnetic field inside a toroid which is a good example of power of Amper's law.

The current enclosed by the dashed line is just the number of loop times the current in each loop. We can show from Amper's law for toroid systems,

$$\int \mathrm{B} \cdot \mathrm{dS} = \mu_0 \mathrm{iN} \text{ or } \mathrm{B} \cdot 2\pi \mathrm{R} = \mu_0 \mathrm{iN} \rightarrow \mathrm{B}_{\mathrm{toroidal}} = \mu_0 \mathrm{iN} \times 1/2\pi \mathrm{R}$$

where R is the distance from the center of tube to the center of the torus, a and b are radius of hallow cylindrical conductor ($a < R < b$). A the Fig. 1 as shown, elliptic torus of fusion design cross-section R, major radius, $r = (b - R)$minor radius. In the geometry, a torus is a surface of motion generated by revolving a circle in 3-D space. A torus can be shown mathematical format,

$$x(\theta, \phi) = (R + r\cos\phi)\cos\theta;\ y(\theta, \phi) = (R + r\cos\phi)\sin\theta \text{ and } z(\theta, \phi) = r\sin\phi$$

where, $0 \leq \phi \leq 2\pi$ and $0 \leq \theta \leq 2\pi$ angles.

r is the minor radius of the toroid and R is the distance from the center of tube to the center of the torus. The ratio

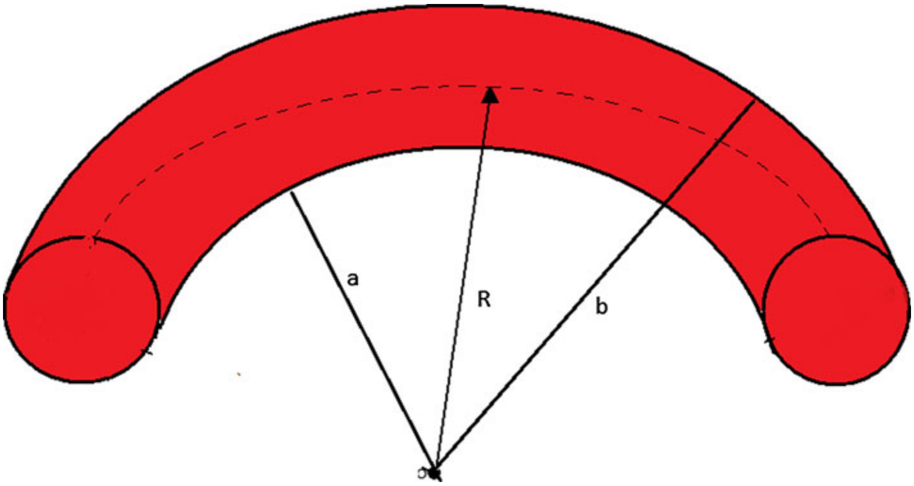


Fig. 1 Elliptic torus of fusion design cross-section [11]

of the two is known as "aspect ratio". An completely equation in Cartesian coordinates for a torus racially symmetric about the z-axis is,

$$\left[R-\left(X^2+Y^2\right)^{1/2}\right]^2+Z^2=r^2,$$

algebraically eliminating the square root gives a quartic equation of the fourth degree is an equating to zero a quartic polynominal, of the form;

$$f(x)=ax^4+bx^3+cx^2+dx+c,\ \ a\neq 0,$$

the surface area and interior volume of this torus are easily computed using pappus's centrtroid theorem. The torus of surface and volumes can be shown A and V, respectively

$$A=4\pi^2Rr=(2\pi r)(2\pi R)\text{ and }V=2\pi^2Rr^2=\left(\pi r^2\right)(2\pi R).$$

This formulas are the same as for a cylinder of length 2πR and radius r. The torus has a generalization to n-dimensional torus, which is the product of n circles, that is $T^n = s^1 \times s^1 \times s^1 \times \ldots \times s^1$.

Transfer of coolants is very important in toroidal hybrid reactor system, because it effect the neutronic performance of the reactors remarkably. In DT driven fusion reactors, lithium bearing coolants should be used to breed adequate tritium for the fusion driver as well as to transfer nuclear heat out of the blanket. Practical candidates are the liquid metals, lithium, $Li1_7PB_{83}$ and Li–Sn and the molten salts, Flibe and Flinabe.

The important properties for these candidate tritium breeders are given in Table 1 [3, 4].

Tritium Breeding Ratio (TBR) and Energy Multiplication

In order to keep the fusion reactions in the plasma to be continuing in the fusion reactors, The speed of tritium breeding (TBR) should be kept above a certain value. To provide this, appropriate materials that contain lithium are placed around the plasma. As tritium is an artificial fusible fuel, a commercial fusion power plant must produce its own tritium. In order for the hybrid reactor to work itself in terms of tritium, TBR should be higher than 1,05Tritium can be extracted from the breeding reaction of ^{6}Li and ^{7}Li isotopes in the blanket as shown,

$$^6\mathrm{Li}+{}^1\mathrm{n}\rightarrow{}^3\mathrm{H}+{}^4\mathrm{He}+(4.784\,\mathrm{MeV})\text{ and }{}^7\mathrm{Li}+{}^1\mathrm{n}\rightarrow{}^3\mathrm{H}+{}^4\mathrm{He}+{}^1\mathrm{n}(-2.467\,\mathrm{MeV})$$

Table 1 Properties of liquid parameters [3, 4]

Property	Li	$Li_{17}Pb_{83}$	Li2BeF4	Li20Sn80	Flinabe
Melting point (°C)	180	235	459	330	300
Density (g/cm^3)	0.48	8.98	2.00	6.20	2.00
Li density (g/cm^3)	0.48	0.062	0.28	0.09	0.12
Tritium solubility	High	Very low	Very low	–	–

The only practical liquids for first wall and blanket are lithium, lead–lithium, Flibe, and Li–Sn, Flowing liquid metals may require the use of electrical insulators to overcome the MHD drag, while for Flibe free surface flows, MHD (magneto hydrodynamics) effects caused by the interaction with the mean flow are less significant.

In case Flibe, TBR is maximum with natural lithium-6 enrichment and it is reduced with Li-6 enrichment. Hence, Flibe has advantage of utilizing lithium without enrichment. The energy multiplication factor (M) is defined as the ratio of the total energy deposited in the system to the incident neutron energy. About 80 % of fusion energy, 14.1 MeV, is carried with neutron that penetrates the first wall and blanket and dissipates its energy through exothermic nuclear reactions. M can simply be defined as below [3, 4].

$$M=[\![200\cdot\langle\Phi\cdot\Sigma_F\rangle+4\cdot 784\cdot T_6-2\cdot 467\cdot T_7+14\cdot 1]\!]\times\frac{1}{17\cdot 6}$$

where $\langle\Phi\cdot\Sigma_F\rangle=\iint\Phi\bullet\Sigma_f\mathrm{d}E\,\mathrm{d}V=$ total integral fission rate,

$$T_6=\iint\Phi\bullet\Sigma_{(n,\alpha)T}\mathrm{d}E\,\mathrm{d}V\text{ on }{}^6\mathrm{Li}\text{ and}$$

$$T_7=\iint\Phi\bullet\Sigma_{(n,n'\alpha)T}\mathrm{d}E\,\mathrm{d}V\text{ on }{}^7Li.$$

The presence of uranium or thorium in the in the liquid first wall and blanket on the other hand, provides additional energy generation through fission reactions with fusion neutrons. In case the first wall that faces is constructional material (solid material), even if the necessary amount of tritium breeding is obtained, the damages that will occur at the wall does not deem the usage of solid walls as convenient as is necessary. This wall will be exposed to the high energy neutron flow that is radiated from the plasma and the positions of the atoms will be changed due to the collision of the neutrons and the atoms which form the structural material and as a result of the nuclear reactions of the (n,p), (n,t), (n,α) and (n,d) gas production will occur in this material. In case the proton isotopes that are radiated at the nuclear reactions that have occurred in the structural material possesses sufficient energy, they can get out of the structural material but alpha particles cannot manage this and form helium gas spheres within the structural material. About 80 % of the heat produced by the reactor systems is collected in the blanket [2].

Fissile Fuel Production

The fissile fuel production calculations are done for a neutron wall load of 10 MW/m^2 fissile fuel production rates of $^{238}U(n,\gamma)^{239}Pu$ and $^{232}Th(n,\gamma)^{233}U$ increase almost linearly with increased heavy metal content [1, 3].

A substantial amount of fissile fuel would be produced by using heavy metal molten salt. The fissile fuel production results from the fertile-fissile conversion with (n,γ) reaction in the fertile blanket, and tritium breeding takes place in the tritium breeding zone, which is positioned behind the fuel layer and contains Li_2BeF_4. The production of fissile fuel from the fertile fuel in the fuel zone of the blanket results from the following fission reaction. The neutron, which is on the left-hand side of equation, n starts the reaction, is a fast neutron, is the DT fusion reaction. Utilization of the molten salt mixture Flibe + ThF_4 produces the precious nuclear fuel ^{233}U the ^{239}Pu fissile fuel can be produced by $^{238}U(n,\gamma)^{239}Pu$ reaction.

$$Fertile\ Fuel + n \rightarrow Fissile\ Fuel + vn' + 200\,\mathrm{MeV}$$

The temporal change of the atomic densities of the fissionable fuel components during hybrid reactor plant operation is evaluated at discrete time intervals Δt under consideration of the nuclear reactions and radioactive transformation processes. Breeding reaction:

$$\Delta c_2 = \Delta t.\left[\mathrm{PF}\cdot c_1\int \sigma(\mathrm{E})\Phi(\mathrm{E})\mathrm{De} + \tau\, c_1\right],$$

indices 1 and 2 show mother and daughter isotopes respectively.

For depletion reactions, where Δc, atomic density change; PF, Plant factor; [3, 4]

$$\Delta c = \Delta t.\left[\mathrm{PF}\cdot c\int \sigma(\mathrm{E})\Phi(\mathrm{E})\mathrm{De} + \tau\ c_1\right]$$

APEX Hybrid Blanket Concepts

The apex study was initiated as part of the US Fusion energy sciences program initiative to identify a vision for an attractive fusion energy system [5]. In this study, Flibe and thin-lityum salt solutions are used in the liquid wall of the reactor. The results obtained for both salt solutions are compared. At the construction of the liquid wall, it is possible to use liquid metals but it might be necessary to use electric isolators to manage magnetic-hydrodynamic drafts at the liquid metal flows, and as this will affect the plasma stability which maintains vital importance for fusion reactors, is an important disadvantage for the usage of liquid metals. MHD impacts are quite unimportant for Flibe and thin-Lityum salt solutions. It is important that the surface vapors pressure of the salt that is used as liquid wall is low. The liquid metal thin-Lityum salt has been included in the APEX studies due to its relatively low surface vapors pressure particularity even at high temperatures. The liquid viscosity and vapors pressure increases in salt solutions along with the BF_2 concentration. Thus, when choosing salts, salts which have low melting point and low BF2 concentrations are preferred. In terms of these problems which will occur in case of structural materials being used, liquid first wall concept is more suitable choice in APEX fusion reactors. At the APEX fusion reactor a fast flowing thin liquid wall has replaced the solid first wall concept of the traditional reactors. Behind the fast flowing thin liquid wall, a slower and thicker second liquid wall (coat) is present. While the liquid first wall traps the charged particles radiating from the plasma, the thick liquid wall at the behind traps the energy and converts it into heat. Liquid wall concept has these important advantages compared to the traditional solid wall concept; with its feature of renewable wall it provides possibility for high power density. There are lithium-containing entrant liquids for the walls: (a) Flibe-well neutron absorber and low electrically conducting medium of molten salt; (b) lithium-a low Z material that is more likely compatible with the plasma operation; and(c) tin-lithium($Li_{20}Sn_{80}$)-an extremely low vapor pressure fluid at elevated temperatures. Both lithium and tin-lithium are good electric conductors [6].

Has better tritium potential reduces the radiation damage and activation on the structural materials significantly from the neutronic angle, Facilitates the maintenance of the equipments inside the reactor cover. Reduces the problems and damages related to the materials in the reactor. At Fig. 2, Temperature values at various points for Flibe liquid flow are given as Degrees Centigrade (°C). According to this when the entrance degree of the liquid to the system is 500 °C, the surface temperature at the exit is around 600 °C. The numbers illustrated on the torus cross section are the symbols given to the surface and cells in the MCNP-4b computer software. The innermost area at the figure consists of plasma and cavities. This is followed by liquid wall, coat, steel wall, armor, stainless steel, vacuum vessel and stainless steel areas consequently. According to the model, the radius of the torus is 552 cm and small radius is 143 cm. the height of the torus is measured as 250 cm from the first liquid wall center has better tritium potential, reduces the radiation damage and activation on the structural materials significantly from the neutronic angle, reduces the problems and damages related to the materials in the reactor. In order to keep the liquid in

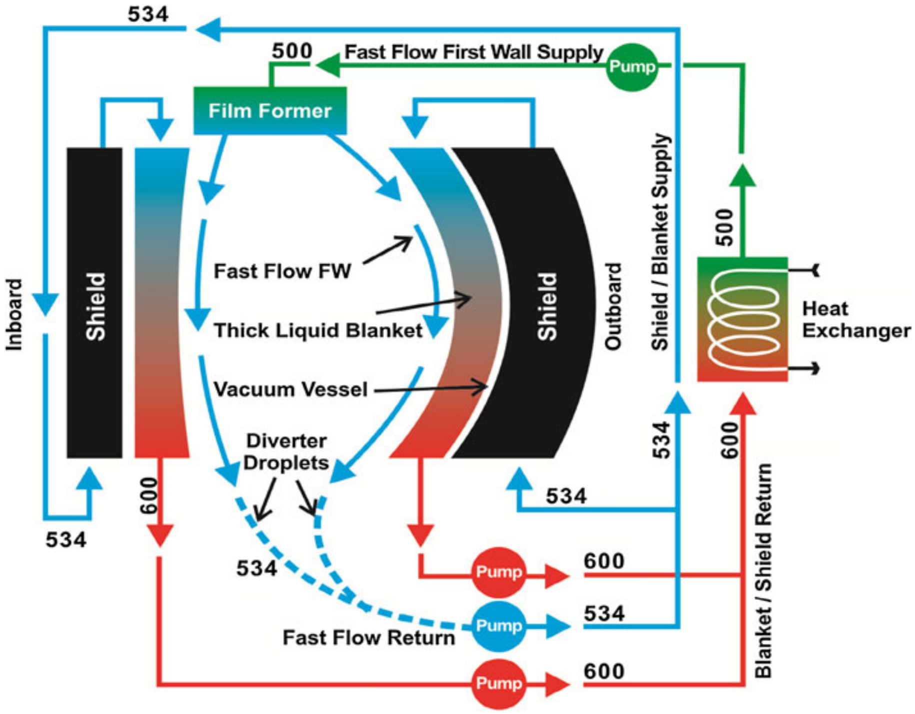


Fig. 2 Temperature chart for liquid flow [5]

balance by this method, the centripetal force has to be bigger then gravita force. When this condition is met, the liquid is injected to the wall with a tangential angle. The liquid which sticks to the leaning wall by the effect of the centripetal force is collected at the base of the ring and drained to a channel. Another method of retention is Electromagnetic retention (EMR) which is only applied to liquid metals and have only been used for lithium blanket at the tokamak configuration. Along with the forces used to keep the liquid stable, the thickness of the used liquid also creates a difference at the construction of the liquid wall. Although both thick and thin liquid walls are eligible to eliminate high surface heat flow, the force of depth of the neutrons in the liquid wall before having reached the back wall shows differences for both wall structures. At the thick liquid wall, the radiation damage that the neutrons may cause by passing through the liquid wall to the structural materials at the back and activation are at far less dimensions compared to the thin liquid wall [3]. conductivity (MHD) deems the effects unimportant, good neutron. However, the attributes of high boiling point 495 °C, low thermal conductivity and wide tritium penetration should be taken into consideration.

Heat Deposition

The main purpose of APEX study is to develop a concept that has the ability for a high neutron wall load (NWL) and related surface heat flux (>10 MW and >2 MW/m^2). The profiles for the heat deposition rates across the Li/V-alloy and Flibe/FS systems were produced as function of the Li-6 enrichment. On account of the higher mildness power of the Flibe, less neutron and gamma rays reach the back situation and by this lower heating rates appear steeper profiles. At natural Li, the maximum power density in the liquid layer is about 60 MW/m^3(flibe), and 40 MW/m^3(Li) [7]. The liquit layer must be thick enough to reduce the neutron induced damage to the structural members so that they will last the life of reactor Displacements per Atom (DPA) are a mesure of neutron damage [7, 8].

Numerical Calculations

MCNP computer software provides instruments to solve nuclear problems by simulating the neutron activities. The APEX fusion reactor used in this study has been designed in 3 dimensional torus shape by using the MCNP-4B computer software that uses the Monte Carlo technique, using the ARIES-RS reactor model which has been realized in the scope of APEX studies. As shown in Tables 2 and 3, by using MCNP-4b code, we obtain neutronic data either UF4 and ThF4.

The cross section of the APEX which has been modeled by the computer software MCNP-4B can be seen in Fig. 3. In the figure, the numbers illustrated on the torus cross section are the symbols given to the surface and cells in the MCNP-4b computer software. Following modeling, plasma has been designed as neutron source that the inner surface

Table 2 Calculated neutronic result at the blanket of ThF4 (% mol)

ThF4 (% mol)	M	(n,γ)	TBR	Total fission	Total fission neutron breeding
0	1,739449	0,000000	1,227424	0,000000	0,000000
2	1,742355	0,090951	1,167773	0,002493	0,008498
4	1,750408	0,141386	1,122966	0,004975	0,016969
6	1,760502	0,187406	1,087566	0,007418	0,025304
8	1,773300	0,224965	1,060310	0,009877	0,033596
10	1,787573	0,260624	1,034242	0,012275	0,041894
12	1,796771	0,293447	1,001521	0,014606	0,049865

Table 3 Calculated neutronic result at the blanket of UF4 (% mol)

UF4 (% mol)	M	(n,γ)	TBR	Total fission	Total fission neutron breeding
0	1,739449	0,000000	1,227424	0,000000	0,000000
2	1,843493	0,087884	1,172823	0,010133	0,036183
4	1,959874	0,133702	1,158448	0,020251	0,072209
6	2,074655	0,175173	1,139097	0,030377	0,108164
8	2,193454	0,216420	1,130319	0,040554	0,138864
10	2,307206	0,253408	1,107934	0,050669	0,180059
12	2,428811	0,298196	1,101726	0,060970	0,216255

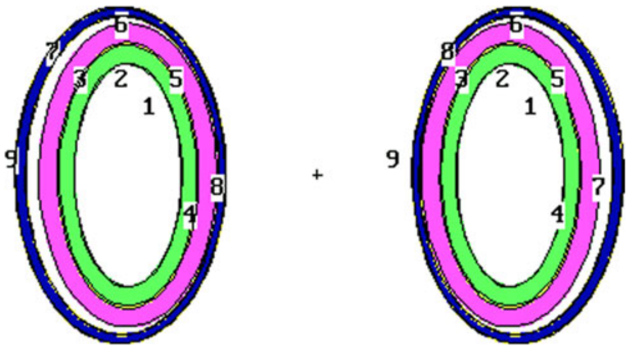


Fig. 3 Inside-out cell and surface cross sections of the APEX model at MCNP-4B [11]

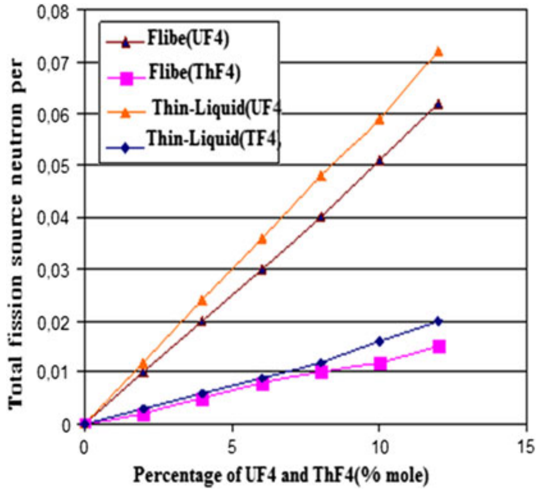


Fig. 4 Variation of the total fissile material production (first wall + blanket + shield area) due to the ratio of UF4 and ThF4

of first liquid wall exposed to neutrons homogeneously and calculations has been conducted with the fusion neutron spectrum [9].

Measured as 250 cm from the first liquid wall center. In the calculations, the plasma liquid has been modelled as the neutron source which the inside surface of the first wall has been subject to homogenously, and the fusion neutron spectrum which has been used for the calculations of both Flibe and thin-Liquid. Fissile fuel production for Flibe and thin-Liquid related to the amount of added fertile fuel are as seen on Fig. 4 The increase of UF_4 veya ThF_4 ratio at the blanket means the increase of the number of ^{238}U and ^{232}Th isotopes in the blanket. Along with this increase, the probability of the colliding of the neutrons emerging from the plasma, increases. It is possible to observe the related transformation for both Flibe and thin-Liquid. Besides, we can observe the collision possibility. The collision number per neutrons and fertile fuel added to the Blanket, total fusion and fissile material increases while tritium production rate decreases. Because of the fertile fuel nucleuses increasing in the blanket, the probability of the interaction of the neutrons that are radiated at the plasma with the lithium isotopes and the TBR ratio related to this, decreases. However, all this argument is valid due the condition that the lithium ratio at the blanket is the decrease that realizes at the TBR is faster for ThF4 than it is for UF4. Although sufficient fuel production can be maintained at the blanket with Torium, sufficient neutron flow cannot be provided because of the fact that the fission rate is low. Due to the richness of Li-6, the variation of the production speed of tritium for Flibe and Thin-Liquid is as shown below at Fig. 6. Related to the UF4 and ThF4 ratios at the blanket, the energy increasing factor for Flibe and thin-Liquid (M) is as seen at Fig. 5. It is observed that the energy increase factor is ascending due to the UF4 and ThF4 ratios blended into the blanket in Flibe and thin-Liquid. As shown in the Fig. 7, we has been calculated by using mcnp4b code, blanket behind FW exposed to neutron Flux with UF4, ThF4 and natural Flibe Conventional first solid wall is exposed barely to the high energy neutrons But, when the first liquid wall is used, the neutron energy and flux that structural material exposed to it is decreased too much as shown in Fig. 7. The neutron energy is decreased from 10 MeV to ev levels. By this, structural material damages are importantly reduced.

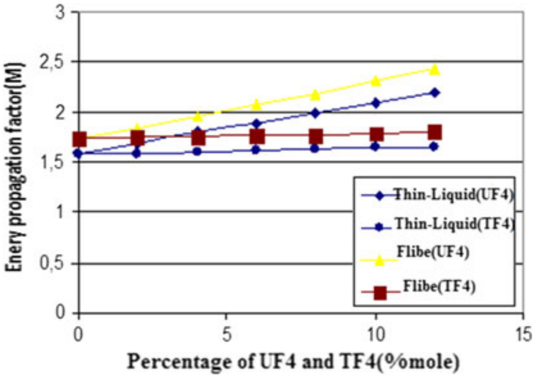


Fig. 5 Propagation factor (M) (liquid wall + blanket + Shield area) changes due to UF4 and ThF4 ratios

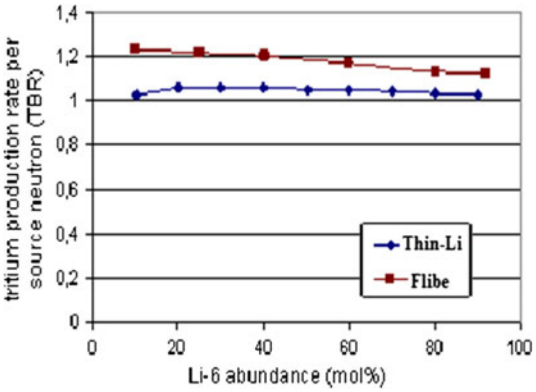
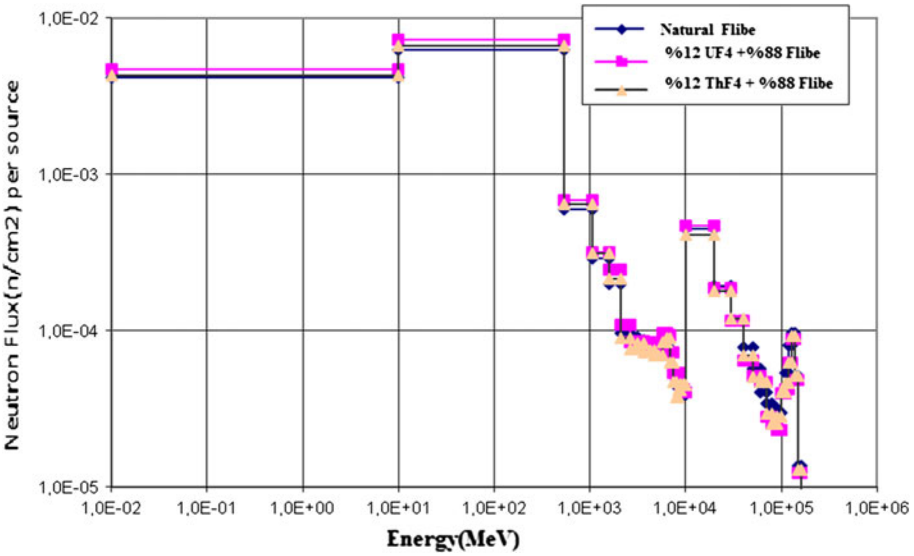


Fig. 6 Variation of the tritium production speed (first wall + blanket + Shield area) for flibe and thin-litium due to the substance of Li-6

Conclusion and Comments

In this study, we have calculated fissile production, tritium production, energy multiplication and neutron flux for toroidal APEX fusion reactor by using MCNP4b code. UF4 and ThF_4 heavy metal salt increased nearly at the same percentage and it has been observed that the percentage of it is practically the same in both materials. In Flibe salt solution, the necessary value for the continuity of the fusion has been obtained until the addition of TBR 8 % ThF_4, afterwards, with the following addition of 10–12 % ThF_4, it has been observed that it was impossible for the reactor to operate. For thin-litium ($Li_{20}Sn_{80}$), it has also been observed that for the ThF_4 ratios over 6 % ThF_4 addition, the reactor did not operate. For thin-litium, it has also been observed that for the ThF_4 ratios over 6 % ThF_4 addition, the reactor did not operate. A UF_4 added APEX hybrid toroid reactor which works with a wall load of 10 MW/m^2 also works about twice as powerful as the original APEX reactor [1, 9, 10]. Besides, the fissile fuel production provided at the reactor is also of great importance. At this reactor working with 10 MW power, a yearly net of 4890,768 kg/year ^{239}Pu may be produced. Taking into consideration that the sales price of Plutonium 238 is

Fig. 7 Blanket behind FW exposed to neutron Flux with UF4, ThF4 and natural Flibe



80.000\$/Kg a yearly nearly total income of \$ 400.000.000 may be obtained. In both flibe and thin-lityum, fissile material production is relatively high due to the fact that the TBR required for 12 % UF_4 is provided. Similarly, at the APEX hybrid toroid working at a wall load of 10 MW/m^2 total load increases approximately by 13 % compared to an original APEX fusion reactors' load (4388MWth). Taking into consideration that the market price of the ^{238}U produced in the blanket is 300.000 kg/\$ and the net uranium-233 amount produced in a year is 5807,787 kg/year nearly total income of \$1770.000.000 may be obtained. Of course in the meantime electric kilowatt-hour cost may be very low in APEX hybrid toroid reactor [3] In fusion and hybrid reactors, it is necessary to provide the TBR $>$ 1,05 terms in order to maintain the continuity of the operation of the reactors. At the situation when there are no additions made to the blanket, the values TBR = 1,24 for flibe and TBR = 1,447 for thin-lituim have calculated.

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