STUDY OF A CONCEPTUAL ACCELERATOR DRIVEN SYSTEM LOADED WITH THORIUM DIOXIDE MIXED WITH TRANSURANIC DIOXIDES IN TRISO PARTICLES

by

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Nuclear spent fuel management is one of the top major subjects in the utilization of nuclear energy. Hence, solutions to this problem have been increasingly researched in recent years. The basic aim of this work is to examine the fissile breeding and transuranic fuel transmutation potentials of a gas cooled accelerator-driven system. In line with this purpose, firstly, the conceptually designed system is optimized by using several target materials and fuel mixtures, from the point of neutronic. Secondly, three different material compositions, namely, pure lead bismuth eutectic (LBE), LBE+natural UO_2, and LBE+15 % enrichment UO_2, are considered as target material. The target zone is separated to two sub-zones but as one within the other. The outer sub-zone is pure LBE target, and the inner sub-zone is either UO_2 or pure LBE target.The UO_2 target sub-zone is cooled with helium gas. Finally, the thorium dioxide mixed with transuranic dioxides, discharged from PWR-MOX spent fuel, in pebbles composed of graphite and TRISO-coated spherical fuel particles, is used for breeding fissile fuel and transmuting transuranic fuels. Three different thorium-transuranic mixtures, (Th, Pu)O_2, (Th, Cm)O_2, (Th, Pu, MA)O_2, are examined with various mixture fractions. The packing fractions of the fuel pebbles in the transmutation core and the tristructural-isotropic coated fuel particles in a pebble are assumed as 60 % and 29 %, respectively. The transmutation core is also cooled with a high-temperature helium coolant. In order to produce high-flux neutrons that penetrate through the transmutation core, the target is exposed to the continuous beams of 1 GeV protons. The computations have been carried out with the high-energy Monte Carlo code MCNPX using the LA150 library. The numerical outcomes show that the examined accelerator-driven system has rather high neutronic data in terms of the energy production and fissile fuel breeding.

Key words: accelerator-driven system, spent fuel transmutation, spallation neutron target, thorium breeder, TRISO fuel

INTRODUCTION

In commercial nuclear reactors, highly radioactive materials occur as high-level wastes. They mainly include transuranic isotopes (Np, Pu, Am, and Cm) and long lived fission products. In most countries, it is preferred that they are buried underground in concrete containers in the sea bed. In addition to this, an improved approach is to transmute these wastes in fusion-fission hybrid reactors or accelerator driven systems (ADS) by driving high-energetic neutron and/or proton source. Lawrence [1] first asserted to transmute thorium to ^{233}U with fast neutrons released from a spallation target bombarded with high-energetic protons. In our previous studies (Yapici [2-4], Yapici *et al*. [5-7]), the potentials of nuclear fuel transmutation and fissile fuel breeding have been investigated in various fusion-fission hybrid reactors fueled with various spent fuels discharged from conventional nuclear reactors.

The simplest procedure in an ADS is the transmutation of nuclear fuels using high energetic proton source. An ADS includes elementarily three parts: (1) high energetic proton accelerator, (2) spallation neutron target (SNT), and (3) sub-critical core containing nuclear fuel or wastes. The target is bombarded with high energetic proton particles to produce several tens of high energetic neutrons, immediately after, these neutrons penetrate to the sub-critical core. In the nuclear waste transmutations, two reactions in the core are mainly considered: (1) neutron capture and (2) fission. In both reactions, the nuclear waste or fuel is transmuted or burned.

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During the recent years, a lot of research works on transmutation of nuclear waste in the ADS have been carried out. Some of them are presented in here. Abanades and Perez-Navarro [8] have presented the transmutation of nuclear waste in an ADS cooled with gas and moderated with graphite. Nuclear wastes are used in the case of TRISO pebble bed. This work shows that plutonium except for ^{242}Pu can be transmuted in ratio of 95 %. Takizuka *et al*. [9] and Tsujimoto *et al*. [10] have analyzed the transmutation of minor actinides (MA) in a lead-bismuth cooled ADS. Study of Takizuka *et al*. denotes that the waste transmutation of 250 kg per year is achieved by 80 % plant factor, and a study of Tsujimoto *et al*. shows that the MA are effectively transmuted and burned in their ADS design in the case of the effective neutron multiplication coefficient, k_{eff} = 0.97. Furthermore, the real number of pebbles fitting in a cylindrical ADS core has been analyzed in detail by Garcia *et al*. [11]. Malyshkin *et al.* [12] have studied only spallation targets containing uranium and americium by modelling designs of spallation targets with Monte Carlo. Several geometries and material compositions have been examined for the spallation targets. All examined designs operate in the case of k_{eff} = 0.5. Numerical results of this paper show that over 4 kg of Am can be burned during the first year of operation. Yapici *et al*. [13] have investigated the neutronic data of various infinite target medium (Lead-bismuth eutectic, mercury, tungsten, uranium, thorium, chromium, copper and beryllium) bombarded with a proton source of 1000 MeV. It is exhibited that the infinite medium approach would lead for real ADS designs.The potentials of nuclear waste transmutation of an ADS cooled with lead-bismuth eutectic (LBE) have been investigated in other studies of Yapici *et al*. [14, 15] for the different configurations and fuel compositions. The results of these studies bring out that the considered ADS has high neutronic data for both nuclear waste transmutation and fissile breeding, besides energy producing. Martinez *et al*. [16] have studied on neutronic characteristics of nuclear waste transmutation of accelerator-driven systems. They assert in this study that high energetic neutrons are required for transmutation of transuraniums (TRU) and long-lived fission products. Ismailov *et al.* [17] have examined a uranium spallation target in accelerator-driven system loaded with MA. They have compared lead-bismuth (PbBi) target with uranium target. They have found that the uranium target limited geometrical size has a better neutron multiplication. Furthermore, various types of ADS have been worked for energy production and transmutation of radioactive wastes [18-28].

COMPUTATIONAL MODEL OF ACCELERATOR DRIVEN SYSTEM

In this work, a conceptual semi-spherical accelerator-driven sub-critical system is considered for transmutation of thorium-dioxide (ThO_2) along with transuranic dioxides ($TRUO_2$) extracted from spent fuels. PWR-MOX fuel (Manson, *et al*. [29], fuel with plutonium recycle, 1000 MW_e reactor, 80 % capacity factor, 33 MWd/kg, 32.5 % thermal efficiency, 150 days after discharge) is considered as the spent fuel. The densities and fractions of the considered fuels are exhibited in tab. 1.

The mixed nuclear fuels, (mixtures of ThO_2 and $TRUO_2$s) are configured as tristructural-isotropic (TRISO)-coated micro spherical fuel particles embedded in carbon matrix pebbles. The MCNP model of the considered ADS is illustrated in fig. 1. As seen in this figure, there are four different zones in the considered ADS:
– spallation neutron target, (SNT),
– transmutation zone, (TZ),
– reflector zone, (RZ), and
– shield zone, (SZ).

Spallation neutron target: mainly, 44.5 % lead (Pb)-55.5 % bismuth (Bi) eutectic (LBE) is used as a target material, which has good neutronic, chemical and thermal properties. Therefore, it is the most chosen target material for ADS implementations. As shown in fig. 1, the target zone is separated to two sub-zone space done within the other: (1) the outer sub-zone is pure LBE target part, and (2) the inner sub-zone is either UO_2 cooled with the helium gas or

Table 1. Isotopic fractions and densities of the materials used in the investigated ADS

Material	Density [gcm^{-3}]	Nuclide	Fraction [%]
LBE	11.344	Pb	44.5
	9.8	Bi	55.5
He	0.1786	He	100
ThO_2	9.88	^{232}Th	100
UO_2	10.54	^{235}U	0.7-15
		^{238}U	99.3-85
*NpO_2	11.10	^{237}Np	100
*PuO_2	11.50	^{238}Pu	3.53535
		^{239}Pu	45.0154
		^{240}Pu	26.3505
		^{241}Pu	15.9640
		^{242}Pu	9.13483
*AmO_2	11.88	^{241}Am	21.5213
		^{243}Am	78.1942
*CmO_2	10.55	^{242}Cm	3.91520
		^{243}Cm	0.04721
		^{244}Cm	85.5422
		^{245}Cm	9.54125
		^{246}Cm	0.95413
Graphite	2.10	^{12}C	100
B_4C	2.52	^{10}B	18.431
		^{11}B	81.569

*Discharged PWR-MOX fuel with plutonium recycle, 1000 MW_e reactor, 80 % capacity factor, 33 MWd/kg, 2.5 % thermal efficiency, 150 days after discharge (ref. Manson *et al*., [29], p. 370, Table 8.5)

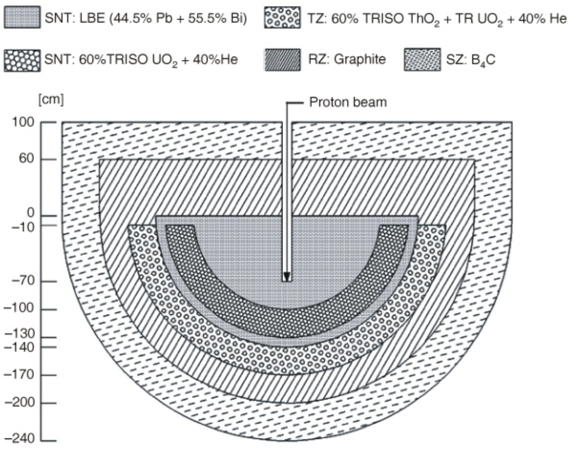

Figure 1. Cross-section of the investigated ADS (SNT: spallation neutron target, TZ: transmutation zone, RZ: reflector zone, SZ: shield zone)

pure LBE target part. Accordingly, three different inner spallation target cases are considered as follows:

Case 1: The inner spallation target part consists of TRISO-coated natural UO_2 particles and is cooled with the helium gas, (coolant volume fraction, $VF_c = 40$ %).

Case 2: The inner spallation target part consists of TRISO-coated 15% enrichment UO_2 particles and is cooled with the helium gas, ($VF_c = 40$%).

Case 3: The inner spallation target part also consists of the pure LBE.

The neutron reactions occur in the spallation target bombarded with high energetic protons, and several tens of neutrons per proton are released in these reactions, depending on incident proton energy. These produced neutrons diffuse through the sub-critical fuel zone to make more reactions.

Transmutation zone: This zone, also named a sub-critical core, contains the mixture of ThO_2 and the transuranic dioxides ($TRUO_2$) to transmute the nuclear wastes and to breed fissile fuel. The TRISO-coated fuel mixture particles, having a high burn-up ability and quite high neutronic performance at high temperatures, are used as nuclear fuel. These particles consist of a fuel kernel in the center, coated with four layers made of three isotropic materials, (1) porous carbon buffer, (2) inner pyrolytic carbon (IPyC), (3) silicon carbide (SiC), and (4) outer pyrolytic (OPyC) [30]. The TRISO fuel particles are embedded in a carbon matrix pebble with a certain packing fraction, and then the pebbles are placed in the TZ with a certain packing fraction. The TRISO packing fraction (PF_t) and the pebble packing fraction (PFp) are assumed as 29 % and 60 %, which can go up to 32 % and 74 % [31] according to packing arrangement, respectively. The spherical geometries of a TRISO fuel particle and carbon matrix pebble are illustrated in fig. 2. This zone is cooled with high-temperature coolant helium, ($VF_c = 40$ %). And also, geometric characteristics of the TRISO particle [31] are given in tab. 2.

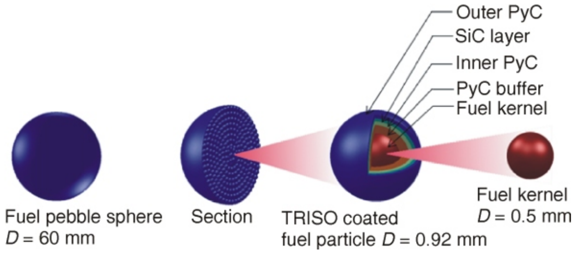

Figure 2. Fuel pebble sphere and TRISO coated fuel particle, (PyC: pyrocarbon, SiC: silicon carbide)

Table 2. Characteristics of TRISO particles [30]

Layer	Size [μm]	Material	Density [g/cm^3]
Fuel kernel	250 (radius)	UO_2	10.55
PyC buffer	95 (thickness)	C/C	1.05
Inner PyC	40 (thickness)	C/C	1.90
SiC layer	35 (thickness)	SiC	3.18
Outer PyC	40 (thickness)	C/C	1.90

Reflector zone: The role of this zone reflects and returns back the energetic neutrons escaping from the TZ, in order to enhance transmutation reactions. For this reason, graphite (carbon) is selected as a reflective material. Scatter cross-section of graphite is comparatively much greater than its absorption cross-section. At the same time, the graphite is a good neutron moderator. Therefore, graphite, also having a high-temperature-resistant property, is largely used in nuclear reactors as an effective moderator and reflector.

Shield zone: This zone is made of boron carbide (B_4C) to absorb the neutrons ultimately escaping from the RZ. B_4C is most commonly preferred and used as an absorbent for neutron radiation in nuclear power plants due to the fact that it has a very high absorption cross-section and excellent thermo-mechanical properties.

It is determined by comparing this semi-spherical configuration with our previous cylindrical configuration in ref. Yapici *et al.* [14] that in the semi-spherical configuration, the value of k_{eff} can reach up 0.98 with lower enrich met of uranium (15 %).

The neutronic computations have been carried out with a high-energy Monte Carlo code MCNPX 2.7 [32] by using the LA150 library [33] which consists of reaction cross-sections for the neutrons from 0.0-150.0 MeV in tabular range for 42 isotopes [32]. Bertini INC model [34] is used for the intra nuclear cascade of spallation reactions.

For each target case (Cases 1-3), three different mixtures of ThO_2 and $TRUO_2$, $(Th, Pu)O_2$, $(Th, Cm)O_2$, $(Th, Pu, MA)O_2$, have been investigated with various mixture fractions (varying in the range of 5%-55%, depending on the fuel composition).In the literature and our previous studies [13,14], it is found out that the gain (G) is maximum in the Case of proton energy $E_p = 1000$ MeV. Hence, proton energy assumed in this study is 1000 MeV. Beside, it is approved that a continuous uniform proton beam, 4 cm in radius, bombards on the target material.

NUMERICAL RESULTS

Neutron multiplication

Neutron multiplication can mainly be provided with two reactions; one is spallation reactions in the target, and the other is the fission reactions of fissile isotopes. In a nuclear system,the number of the produced neutrons is the algebraic sum of generated, captured and leaking neutrons. For a good neutron economy, numbers of captured and leaking neutrons should be optimized. The numerical calculation brings out that the optimum neutron production would be ensured with the target radius of 140 cm.

Figure 3 shows the variations of the produced neutron number (PN) for all target and fuel composition Cases with $TRUO_2$ fraction in the fuel mixtures.

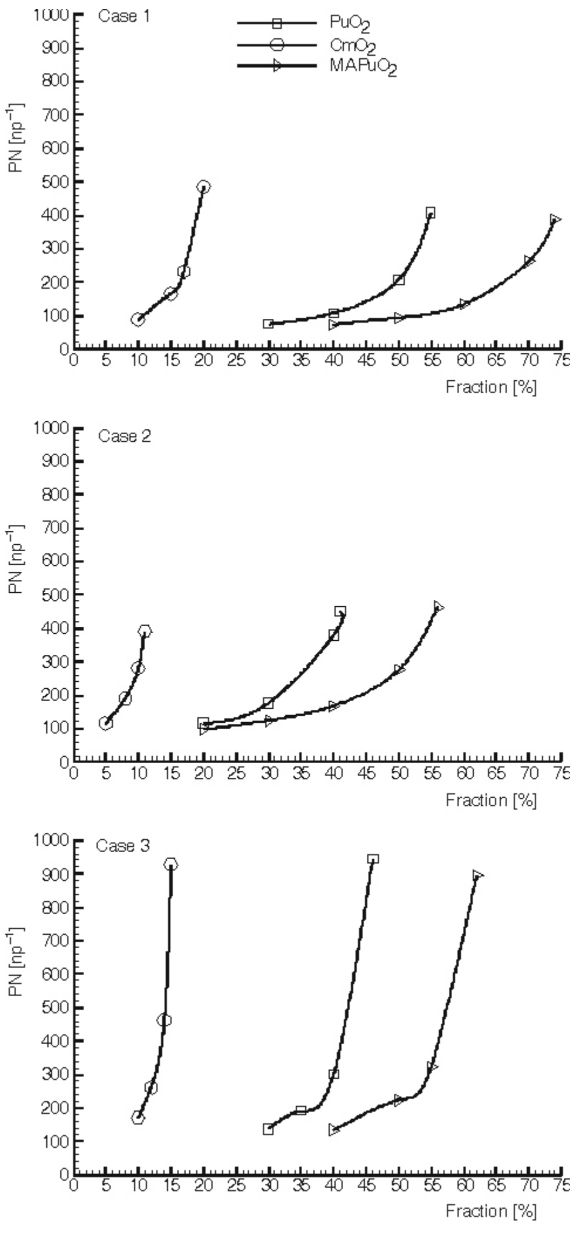

Figure 3. Variations of the neutron production number with the $TRUO_2$ fraction in the fuel mixtures (Th, TRU)O_2

As apparent from this figure, in all target cases, more thorium is utilized in the fuel mixture case of (Th, Cm)O_2. This means that the fissile ^{233}U more breeds, (see eq. 2a). The neutron productions in the target case of pure LBE (Case 3) are about two times those in the other target cases, which means up to 930 neutrons per proton. These results bring out that pure LBE target is more effective, from the point of neutron economy.

Energy gain and effective neutron multiplication coefficient

The effective neutron multiplication coefficient, k_{eff} is defined as the ratio of neutron quantity produced in one generation to the neutron quantity in the preceding one. This coefficient is less than 1 in the sub-critical ADS, (0.95-0.98).In this work, the fuel compositions are adjusted that k_{eff} is provided in the range of 0.80 to 0.98.

The energy gain, *G*, is described as the ratio between the total fission energy production the fuel core and the energy of the proton beam.

$$G = \frac{R_f E_f}{E_p} \qquad (1)$$

where R_f is the number of fission reaction and E_f – the energy per fission (200 MeV).

The variations of *G* and k_{eff} are plotted in fig. 4 *vs*. the $TRUO_2$ fraction in the fuel mixtures for all target and fuel composition cases. The value of *G* can reach up 96 in the Case 3. It is quite a high value in terms of energy multiplication. As in the PN variations, also, the *G* values in the Case 3 are two times those in the other target cases.

Fissile fuel breeding

In the ADS, not only energy production but also fissile fuel breeding is one of priority issues for the optimization of the ADS design. Therefore, the considered ADS is optimized, from the points of both energy production and the fissile fuel breeding. The fissile breeding reactions taken into account in this study are as follows

$$^{232}\mathrm{Th}(n,\gamma)^{233}\mathrm{Th} \xrightarrow{\beta} {}^{233}\mathrm{Pa} \xrightarrow{\beta} {}^{233}\mathrm{U} \qquad (2a)$$

$$^{238}\mathrm{U}(n,\gamma)^{239}\mathrm{U} \xrightarrow{\beta} {}^{239}\mathrm{Np} \xrightarrow{\beta} {}^{239}\mathrm{Pu} \qquad (2b)$$

$$^{238}\mathrm{Pu}(n,\gamma)^{239}\mathrm{Pu} \qquad (2c)$$

$$^{240}\mathrm{Pu}(n,\gamma)^{241}\mathrm{Pu} \qquad (2d)$$

$$^{242}\mathrm{Pu}(n,\gamma)^{243}\mathrm{Pu} \qquad (2e)$$

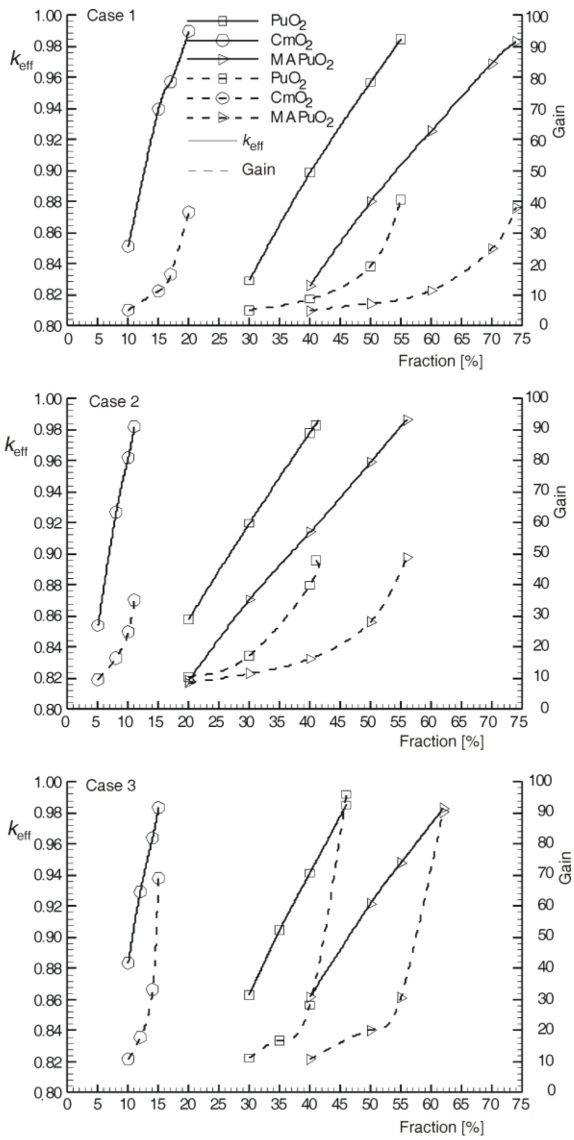

Figure 4. Variations of the energy gain and the effective neutron

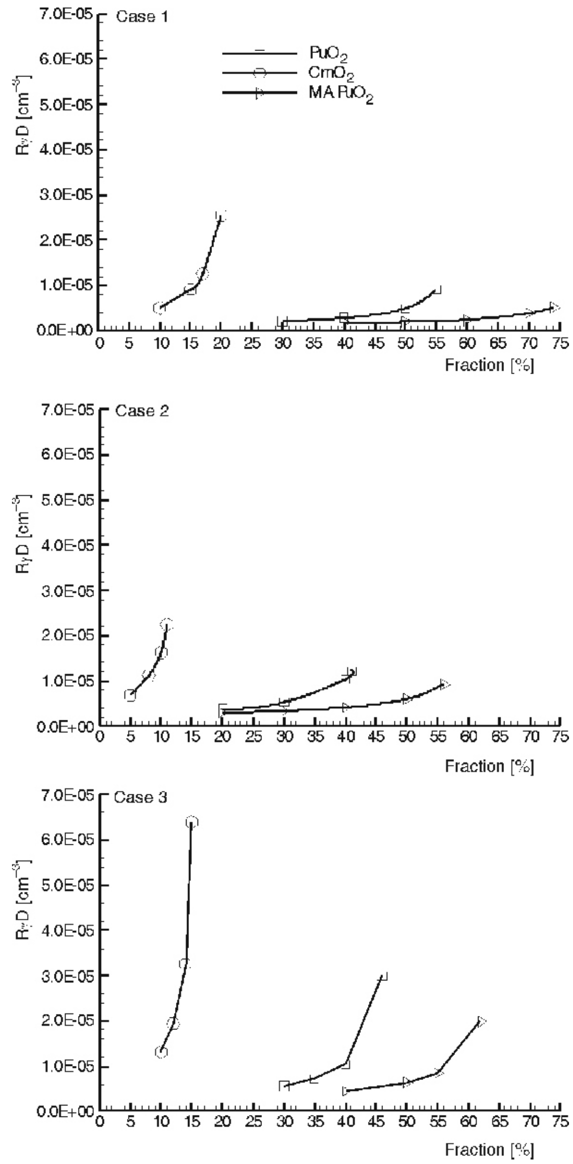

Figure 5. Variations of ^{233}U breeding density with the TRUO$_2$ fraction in the fuel mixtures (Th, TRU)O$_2$

$$^{244}\mathrm{Pu}(n,\gamma)^{245}\mathrm{Pu} \tag{2f}$$

$$^{242}\mathrm{Cm}(n,\gamma)^{243}\mathrm{Cm} \tag{2g}$$

$$^{244}\mathrm{Cm}(n,\gamma)^{245}\mathrm{Cm} \tag{2h}$$

Figure 5 depicts the capture reaction densities of ^{232}Th, which equal to ^{233}U fissile breeding densities (see eq. 2a), *vs*. the TRUO$_2$ fraction in the fuel mixtures for all target and fuel composition cases. In all target cases, the production of ^{233}U in the fuel mixture case of (Th, Cm)O$_2$ is much higher than that in the other fuel mixture cases, (about 2.5 times), and thorium in this fuel mixture case is much more utilized than that in the other fuel mixture cases.

Figure 6(a) shows ^{239}Pu fissile breeding densities obtained from the capture of ^{238}U (see eq. 2(b)) in the inner target zone, versus the TRUO$_2$ fraction in the fuel mixtures for target Case 1, Case 2, and all fuel composition cases. The values of these breeding densities are close to each other. Nonetheless, in the target Case 2, it is seen that these values are reached at lower TRUO$_2$ fraction in the fuel mixtures.In addition to this figure, the ^{239}Pu fissile breeding densities obtained from the capture of ^{238}Pu (see eq. 2(c)) in the TZ are plotted in fig. 6(b). As is apparent from this figure, the highest values of ^{239}Pu fissile breeding are obtained in the target Case 3.

The other fissile fuel breeding densities, ^{241}Pu, ^{243}Pu, ^{243}Cm, and ^{245}Cm, are demonstrated in figs. 7-10, respectively. These breeding reactions are given with eqs. (2d-h). As shown in fig. 7, as the values of ^{241}Pu breeding densities in the fuel mixture cases of (Th, Pu)O$_2$ and (Th, MA, Pu)O$_2$ are almost the same in the targets Cases 1, 2, those values are about 2.5 times in the targets Case 3.This situation applies also for val-

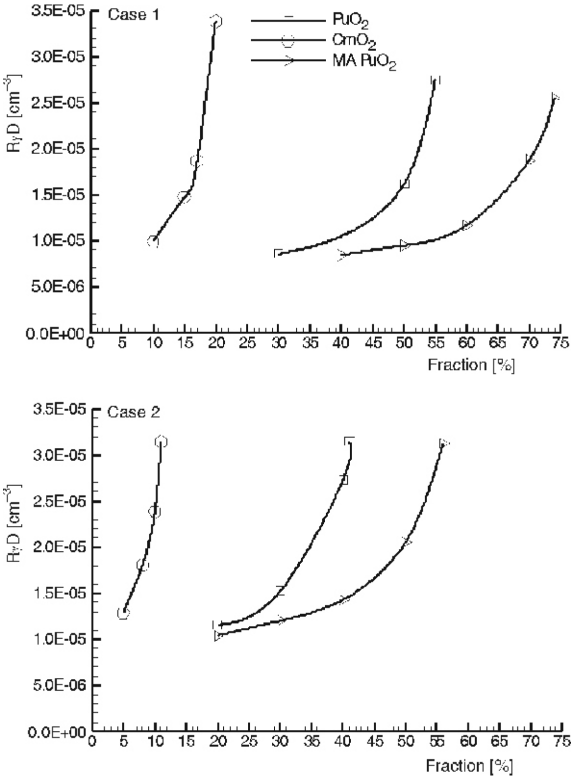

Figure 6(a). Variations of ^{239}Pu breeding density with the TRUO$_2$ fraction in the fuel mixtures (Th, TRU)O$_2$ at the inner sub-zone of the target zone

ues of ^{243}Pu breeding densities (see fig. 8). The values of ^{243}Cm and ^{245}Cm breeding densities in the fuel mixture Case of (Th, MA, Pu)O$_2$ are quite low (near-zero) in all target cases. In sum, the fissile breeding figures show that the best target CASE is pure LBE target (Case 3).

Furthermore, the values of all fissile fuel breedings (in g/d) in the Case of $k_{\rm eff}$ = 0.98 for proton intensity (PI) of 10^{17} s^{-1} are given in tab. 3. The ^{239}Pu, ^{241}Pu, and ^{243}Pu fissile fuels can be bred up to 776 g in a day. As for the thorium utilization meaning fissile ^{233}U breeding, this value can reach up to 905 g in a day. The values of total fissile fuel breeding are in the range of 510-1459 g/day. In brief, the numerical results confirm that the best target case is the pure LBE target and the best fuel mixture case is (Th, Cm)O$_2$, in terms of total fissile fuel breeding.

Thermal power

In this study, PI is assumed as 10^{17} protons/s having energy of a 1000 MeV. According to these values, the proton beam power (PP in MW) and thermal power ($P_{\rm th}$ in MW) can be calculated

$$PP \quad C_{\rm f}E_{\rm p}PF\ 10^{\ 6} \tag{3a}$$

$$P_{\rm th} \quad GPP \tag{3b}$$

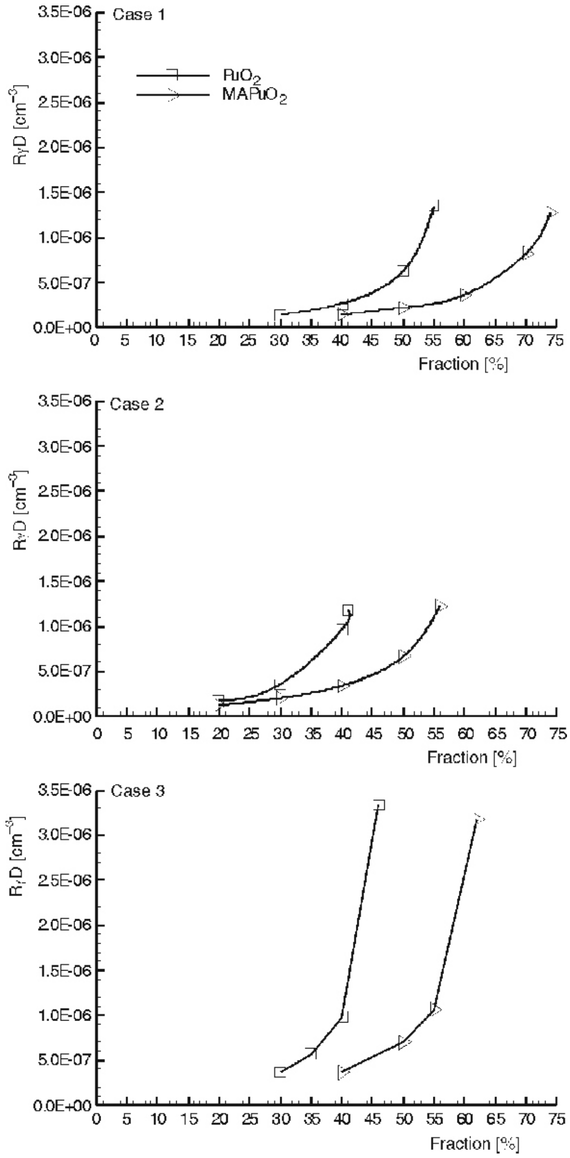

Figure 6(b). Variations of ^{239}Pu breeding density with the TRUO$_2$ fraction in the fuel mixtures (Th, TRU)O$_2$ at the transmutation zone

where $C_{\rm f}$ is conversion factor and equals to $C_{\rm f}$ = = 1.602210^{-13} J/MeV.

For $k_{\rm eff}$ = 0.98 and PI = 1017 protons/s, the values of G and $P_{\rm th}$ are given in tab. 3. The value of G varies in the range of 35 to 96. $P_{\rm th}$ varies in the range of 562 to 1540 MW, depending on the values of G. In the Case of pure LBE target, the values of $P_{\rm th}$ are above 1000 MW. Consequently, as regards thermal power, the pure LBE target and the fuel mixture Case (Th, Pu)O$_2$, proved as the best configuration.

CONCLUSIONS

A conceptual semi-spherical ADS has been investigated to transmute TRU and thorium, and to breed fissile fuel as well as energy production. The several design structures and fuel mixtures have

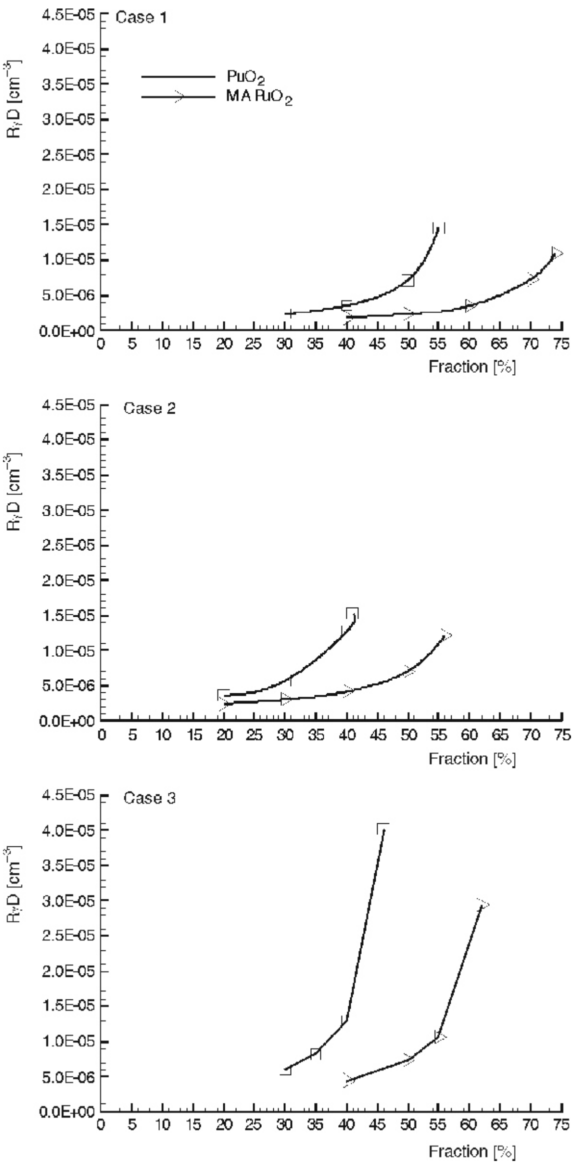

Figure 7. Variations of ^{241}Pu breeding density with the $TRUO_2$ fraction in the fuel mixtures (Th, TRU)O_2

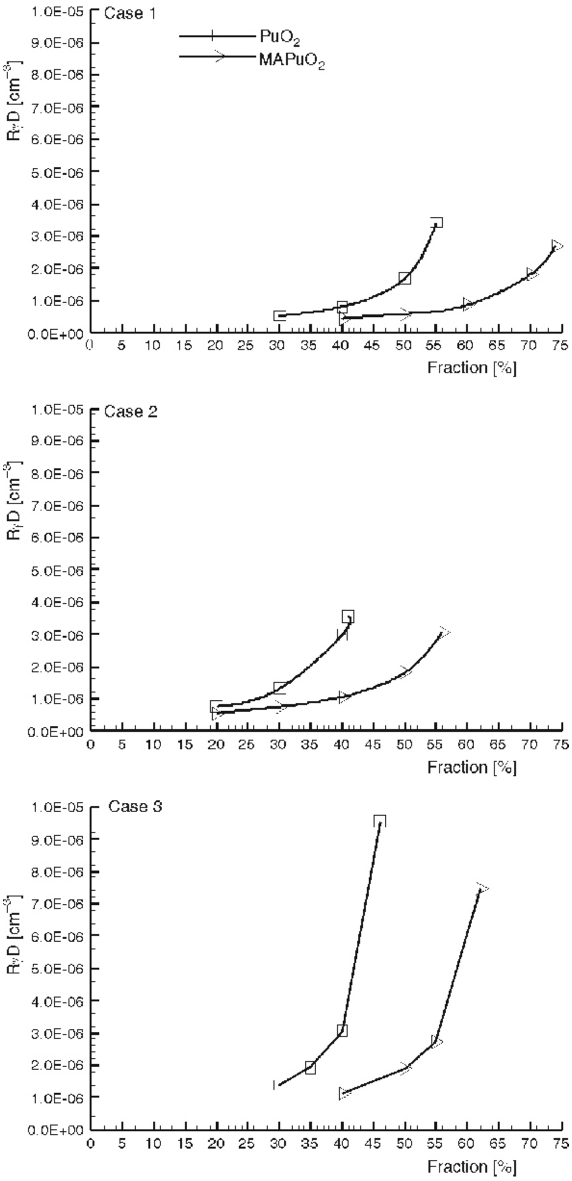

Figure 8. Variatons of ^{243}Pu breeding density with the $TRUO_2$ fraction in the fuel mixtures (Th, TRU)O_2

been analyzed from the points of transmutation and energy production. In brief, the main conclusions are: the pure LBE target, which is one of the examined targets, is the best target Case in terms of neutronic performance. Significant amount of thorium is utilized for production of fissile ^{233}U. Total fissile fuel breeding is in the range of 510-1459 g per day. The best (Th, TRU)O_2 fuel mixture is (Th,

Table 3. Neutronic data in the CASE of k_{eff} = 0.98 for PI = 10^{17} protons/s which corresponds 16.02 MW

SNT Case	Fuel mixture (ThO_2 + $TRUO_2$)	*Fraction [%]	G	P_{th} [MW]	Fissile fuel breeding [gd^{-1}]						
					^{233}U	^{239}Pu	^{241}Pu	^{243}Pu	^{243}Cm	^{245}Cm	Total
1	ThO_2 + PuO_2	55.0	41	648	128.4	234.4	213.0	50.3	–	–	626
	ThO_2 + CmO_2	20.0	37	583	359.6	264.5	–	–	9.66	269.6	903
	ThO_2 + (Pu + MA)O_2	74.0	38	609	71.7	217.8	161.3	39.8	0.5	18.8	510
2	ThO_2 + PuO_2	41.0	48	769	173.1	263.0	222.9	52.6	–	–	712
	ThO_2 + CmO_2	11.2	35	562	317.9	246.0	–	–	4.5	145.2	714
	ThO_2 + (Pu + MA)O_2	56.0	49	781	131.0	262.0	177.6	45.5	0.5	19.9	636
3	ThO_2 + PuO_2	46.0	96	1540	423.8	48.4	587.0	140.8	–	–	1200
	ThO_2 + CmO_2	15.2	69	1105	905.0	–	–	–	17.8	535.8	1459
	ThO_2 + (Pu + MA)O_2	62.0	90	1446	279.9	46.1	430.3	110.0	1.25	49.1	917

* Fraction of $TRUO_2$ in the fuel mixture

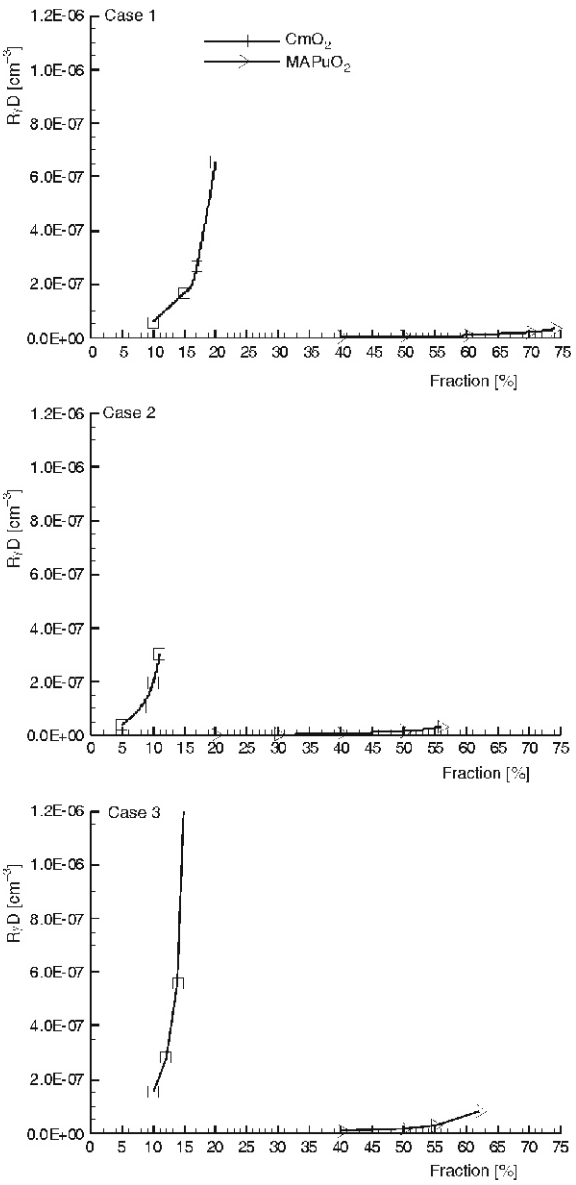

Figure 9. Variations of ^{243}Cm breeding density with the $TRUO_2$ fraction in the fuel mixtures $(Th, TRU)O_2$

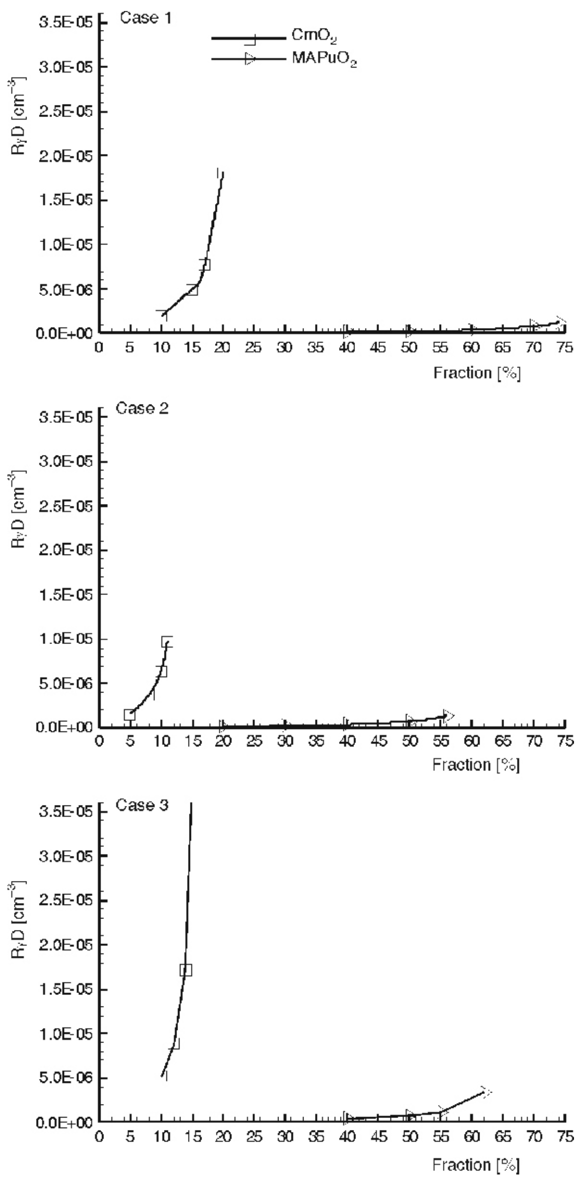

Figure 10. Variations of ^{245}Cm breeding density

$Cm)O_2$ in terms of total fissile fuel breeding. The value of G would reach up to 96 that is quite a high value. The values of P_{th} are above 1000 MW in the Case of pure LBE target and would reach up to 1540 MW. Consequently, the examined semi-spherical gas-cooled ADS has rather high neutronic performance for an effective energy production and transmutation of nuclear fuel wastes, and this ADS configuration can perform more effective transmutation of spent fuel by using lower enrichment of uranium, in comparison with our previous cylindrical configuration in ref. Yapici *et al*. [14].

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AUTHORS' CONTRIBUTIONS

Theoretical and numerical analyses were carried out by H. Yapici and G. Bakir. G. Bakir and G. Genc analyzed and discussed the results. The manuscript was written and the figures prepared by all authors.

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СТУДИЈА ИДЕЈНОГ ПРОЈЕКТА СИСТЕМА УПРАВЉАНОГ АКЦЕЛЕРАТОРОМ, ИСПУЊЕНОГ ТОРИЈУМДИОКСИДОМ СА ТРАНСУРАНСКИМ ДИОКСИДИМА У ВИДУ TRISO ЕЛЕМЕНАТА

Управљање утрошеним нуклеарним горивом једна је од главних тема у коришћењу нуклеарне енергије, те су последњих година решења овог проблема упорно истраживана. Циљ овог рада је да се испита фисиона оплодња и потенцијали трансмутације трансуранског горива у гасом хлађеном систему управљаном акцелератором. Са неутронског гледишта, најпре је концептуално пројектовани систем управљан акцелератором оптимизован коришћењем више материјала мете и мешавина горива. Потом су као мете разматране три композиције материјала: чист олово бизмут еутектик (LBE), LBE са природним UO_2 и LBE са 15 % обогаћеним UO_2. Зона мете раздвојена је на две подзоне, са једном подзоном унутар друге. Спољашња под зона је чиста LBE мета, док је унутрашња – или UO_2 или чиста LBE мета. UO_2 подзона хлађена је гасом хелијума. Најзад, мешавина торијумдиоксида са трансуранским диоксидима, издвојена из PWR-MOX утрошеног горива у виду кугли сачињених од графита и триструктурално-изотропних (TRISO)-обавијених сферних горивних елемената, коришћена је за оплодњу фисионог горива и трансмутацију трансуранских горива. Испитане су три различите торијум-трансуранске смесе, $(Th, Pu)O_2$, $(Th, Cm)O_2$ и $(Th, Pu, MA)O_2$, са различитим фракцијама компоненти. Претпостављено је да фракције паковања горивних кугли у трансмутационом језгру и TRISO-обавијеним горивним елементима у кугли, износе 60 % и 29 %, респективно. Трансмутационо језгро такође је хлађено високотемпературним хелијумским хладиоцем. У циљу стварања високог неутронског флукса ради продирања кроз трансмутационо језгро, мета је изложена континуалном снопу протона енергије 1 GeV. Прорачуни су обављени MCNPX Монте Карло кодом за високе енергије коришћењем LA150 библиотеке. Нумерички резултати показују да разматрани акцелератором управљани систем има високе неутронске одлике у смислу стварања енергије и оплодње фисибилног горива.

Кључне речи: систем управљан акцелератором, трансмутација утрошеног горива, спалација неутронске мете, оплодња торијума, TRISO гориво