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Nuclear Design and Analysis of a Magnetic Fusion Production Reactor[1]

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Tandem-mirror- and tokamak-based magnetic fusion production reactors are predicted to have tritium breeding ratios of 1.67 and 1.49, respectively. The latter value replaces one (1.56) that is used elsewhere in the sequence of papers in this issue. Blanket energy multiplication for both is predicted to be about 1.3. With the tandem mirror operating in the plutonium production mode, the net plutonium-plus-tritium breeding ratio is 1.74. Blanket energy multiplication for the plutonium mode is predicted to be 2.4 at a plutonium–uranium ratio of 0.7% and a uranium volume fraction of 3%.

KEY WORDS: magnetic fusion production reactor; tritium production; fusion breeder; nuclear analysis.

INTRODUCTION

Like the others in this series, this paper evaluates, in a preliminary way, the potential of magnetic fusion for producing (or breeding) special nuclear materials (SNM).$^{(1)}$

The fusion of deuterium (D) and tritium (T) is a source of high-energy neutrons

$$\mathrm{D}+\mathrm{T} \underset{\text{fusion}}{\rightarrow} \alpha(3.6\ \mathrm{MeV})+n(14.1\ \mathrm{MeV})$$

Excess neutrons can, in addition to breeding the tritium consumed by D–T fusion, be made available to breed excess tritium and/or plutonium (Pu). These excess neutrons can be produced in a number of ways with energetic neutrons. For example, they can be produced by the (n, n′T) reaction in lithium-7 (^{7}Li), by (n, 2n) reactions in beryllium (Be) or lead (Pb), and by (n, fission) plus some (n, 2n) and (n, 3n) reactions in uranium-238 (^{238}U) and thorium-232 (^{232}Th). We chose Be(n, 2n) for neutron multiplication in this conceptual design study because it results in a higher breeding ratio than either ^{7}Li or Pb does and does not have the safety implications inherent with fission.$^{(2)}$ Tritium breeding in infinite media of Be, ^{7}Li, and Pb (+6 at% ^{6}L$_i$) is calculated to be 2.7, 1.8, and 1.7, respectively.

Breeding occurs in the "blanket," a region surrounding the fusion "core." The nuclear design and analysis of a blanket that produces SNMs (tritium and/or plutonium) is the subject of this report. Other nuclear parameters important in blanket design and analysis are energy multiplication, power density, fissile buildup, and isotopic composition. Although the basic nuclear objective of the blanket is to maximize breeding, blanket structure, heat transfer, and fuel handling requirements must be met. Thus, an interactive and iterative design process is required.

If nuclear performance were the only design requirement, the blanket would consist of Be plus a few atom percent lithium-6 (or ^{6}Li + ^{238}U) and its breeding ratio would be about 2.7.$^{(3)}$ Thus, the blanket's potential nuclear performance is high. The

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[1] This paper represents work carried out from 1980 to 1982 and was in draft form in 1982. It was received for publication with only minor editing of its 1982 version, explaining the fact that some of the material is dated.

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question is how well the blanket can perform when structure, heat transfer, and other requirements are met. To answer this question, one must design, model, and analyze the blanket by neutron and gamma transport methods.

The blanket design that evolved from our study had, as a starting point, two considerations, (1) that Be is a good neutron multiplier, and (2) that proven Savannah River materials technology (aluminum, lithium-aluminum, and water) will be adopted to minimize development time. The design concept that resulted consists mainly of Be (~ 80 vol%), aluminum fuel slugs containing lithium or lithium plus ^{238}U (~ 10 vol%), aluminum for structure and cladding, and low-temperature, low-pressure water for cooling. For a detailed description of the blanket's mechanical design, see Ref. 4.

Two types of magnetic fusion devices—the tandem mirror and tokamak—are under consideration for the magnetic fusion production reactor (MFPR). Although the main emphasis in the work reported here was on the tandem mirror device, estimates for the tokamak were made using a similar blanket. Blankets for the tandem mirror device surround a cylindrical plasma core with a large length-to-diameter ratio ($L \sim 50$ m, $D \sim 1$ m). Those for the tokamak surround a toroidal plasma core with an aspect ratio of about 4 ($R \sim 4$ m, $r \sim 1$ m).

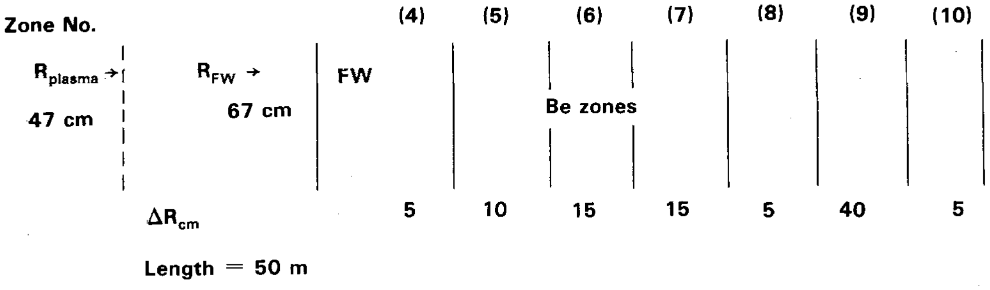
Two of the principal tools used for nuclear analysis of the blanket are TARTNP—a neutron-photon-coupled, three-dimensional, Monte Carlo transport code—and 175 nuclear energy data generated from ENDL, the Livermore-evaluated nuclear data library.(5,6)

MODELING

We developed two geometric blanket models and analyzed them with TARTNP code. The first model was a radial-zoned cylinder of finite length, and the second was a rectangular unit cell. The results from both models are combined to predict the blanket's nuclear performance.

Cylindrical Model

The basic cylindrical model is a nested set of concentric cylindrical shells surrounding a cylindrical volume source of isotopic 14-MeV neutrons (the plasma). Its geometry and composition are shown in Fig. 1. The materials in each zone of the model are homogenized. In zones where the sum of the material volume fractions is less than 1.0, the difference is a void. The Be density is 90% to allow for swelling and/or helium release. The outer surfaces of the



Material volume fractions

Materials > zone No.	Aluminum structure and cladding	H_2O	Beryllium (90 % dense)	Al + 2 wt % ^{6}Li (fuel slugs)
4	0.11	0.05	—	—
5, 6, 7	0.057	0.042	0.80	0.10
8,10	0.15	0.15	—	0.70
9		1.0		

Fig. 1. Cylindrical blanket model showing geometry of composition.

Table I. Cylindrical Model Results

Zone	Reactions and energy per source neutron		
	^{6}Li(n, α)T	Total capture	Energy [MeV(n + γ)]
4	—	0.0022	0.56
5	0.828	0.943	8.61
6	0.757	0.826	6.48
7	0.263	0.283	2.18
8	0.079	0.081	0.51
9	—	0.047	0.36
10	0.001	0.001	0.02
Totals	1.93	2.20	18.72 ($M = 1.33$)
Axial leakage	0.0214 (including 0.014 source neutron)		
Radial leakage	0.0015		
Total leakage	0.0229		

model are radial and axial leakage boundaries. Thus, leakage is overpredicted because net leakage will be less when shields and end-cell plasmas are accounted for.

The number of ^{6}Li(n, α)T tritium breeding reactions and the heating per source neutron (blanket tritium breeding ratio T and energy deposition E) calculated by the TARTNP code with the cylindrical model are $T = 1.93$ and $E = 18.72$ MeV. Results per zone are listed in Table I. Standard deviations are about 3%. Total capture and leakage are 2.20 and 0.0229; therefore, the total number of neutrons per source (14-MeV) neutron is 2.22, of which 87% result in useful captures producing tritium, 12% are parasitic captures, and 1% is lost by leakage. Energy multiplication M is 1.33 (the ratio of E to the source neutron kinetic energy $E/14$ MeV).

A detailed breakdown of neutron reactions in zone 5, the first fuel zone, is given in Table II. The largest single parasitic reaction is the Be(n, α) reaction (0.069/source neutron). The number of parasitics in zone 5 is 0.115, or 12% of total captures. Be(n, α) reactions in zone 5 total 0.744, compared to 0.107 in the outer Be zone. Tritium production in the Be is not included in the useful tritium breeding ratio (*TBR*) because it might be tied up in the Be. The total Be(n, t) is 0.017.

The tritium production rates in each zone relative to the initial ^{6}Li concentrations (T') are listed in Table III for a 1-MW/m^2 wall loading. This is also ^{6}Li "burnup." In the inner zone T' is 18.6%/year and drops to 0.34%/year in the zone just inboard of the water reflector (zone 8).

The power densities in the various radial zones—due to heating by both neutrons and gammas—normalized to a wall loading of 1 MW/m^2 are given in Table IV. The value (0.769 W/cm^3) for the first zone (zone 4) is low because that zone is mostly void. When all the zone 4 heating is concentrated in the aluminum (Al) structure, the Al power density is 7.0 W/cm^3. Heating in the Be zones varies from 5.3 to 0.66 W/cm^3.

Table II. Reactions in Zone 5, the First Be Zone

	Be	Al	^{6}Li	H	O
(n, 2n)	0.744	0.001	$3E-4$	—	—
(n, p)	—	0.009	$9E-5$	—	$5E-4$
(n, d)	—	0.002	0.004[a]	—	$2E-4$
(n, t)	0.012	$1E-6$	0.828	—	—
(n, α)	0.069	0.012	—	—	0.003[a]/0.002
(n, γ)	0.002	0.005	$4E-5$	0.002	0.002

[a] A secondary neutron is also emitted.

Table III. T', Relative Production Rate (T atoms/^{6}Li atom/year)

T'(atoms/atom/year) = $(BR\cdot S_n\cdot t\cdot V^{-1})/N(\text{Li})$
At $\Gamma = 1\text{MW/m}^2, S_n\cdot t = 2.93\times10^{27}$ n/year
$N(^6\text{Li}) = 5.40\times10^{20}$ atoms/cm^3 (zones 5–7)
$= 3.8\times10^{21}$ atoms/cm^3 (zones 8 and 10)

Zone	TBR	$V\times10^{-7}$ cm^3	T' (atoms/atom/year)
5	0.828	2.42	0.186
6	0.757	4.22	0.0973
7	0.263	4.92	0.029
8	0.079	1.80	0.00338
10	0.001	2.51	3.07$E-5$

Table IV. $\ddot{Q}(r)$, Radial Power Density (n + γ), Cylindrical Model, *T*MODE

$\ddot{Q} = \frac{E}{V}\cdot\frac{1}{14.06}\cdot A_{\text{FW}}{}^{a}\cdot\Gamma^{b}$

Zone	ΔR (cm)	E (MeV)	$V\times10^7$ cm^3	$\ddot{Q}$(W/cm^3 at Γ = 1.0 MW/m^2)
4	4	0.56	1.09	0.769(< 6.99 in Al)
5	10	8.61	2.42	5.33
6	15	6.48	4.22	2.30
7	15	2.18	4.92	0.663
8	5	0.51	1.80	0.424
9	40	0.36	17.2	0.031
10	5	0.02	2.51	0.012

[a] A_{FW}(first wall area) = $2\pi r_{\text{FWL}} = 2\cdot\pi\cdot0.67\cdot50 = 210$ m^2.
[b] Γ (neutron wall loading) = 1 MW/m^2.

Unit-Cell Model

The cylindrical model discussed above treats each radial zone as a homogeneous mixture of materials, but there is a question of how well this treatment approximates the actual blanket in which Be, Al, H_2O, and Li–Al fuel slugs are discrete. To address this question, we have constructed a unit-cell model consisting of a Be block with a hemicylindrical cutout containing a Li–Al "fuel" hemicylinder and H_2O (coolant), as shown in Fig. 2. The six outside surfaces of the unit cell are reflecting boundaries; thus, to source (14-MeV) neutrons generated at the bottom of the cell, the cell is an infinite array of unit cells. The source is a plane at the bottom of the cell and has an angular distribution of 0–45° around the Z axis. The TBR calculated for this model is 2.26, but it increases to 2.40 when the materials are homogenized. Thus, it is apparent that the heterogeneous effects are significant. Compared to the heterogeneous case, the homogenized case overpredicts the TBR by 6%. To account for heterogeneous effects in the Be/LiAl zone, results from the two-dimensional cylindrical model will be reduced by 6%. Optimization is required to determine the size and pitch of the LiAl/H_2O tubes needed to maximize breeding, as well as to allow for adequate cooling.

Another potentially important heterogeneous effect is energy partitioning in the Be/H_2O/LiAl zone. Without considering gamma transport, the energy

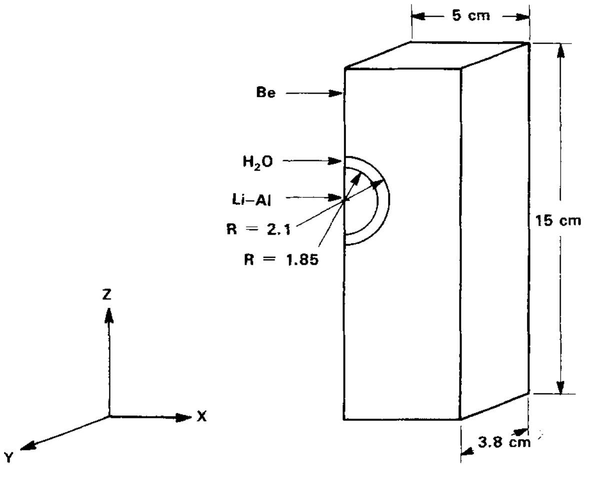


Fig. 2. Unit-cell model.

partitioning for this unit cell is 40% in Be, 5% in H_2O, and 55% in LiAl. When gamma transport is considered, the Be is expected to receive a higher fraction of energy partitioning while the LiAl receives a lower fraction. If 50% of the heating occurs in the Li–Al fuel slugs and they occupy 10% of the volume, peak power density in the Li–Al fuel slugs is

$$Q_{\max} = Q_{\text{zone 5}} \cdot \frac{\text{Energy fraction}}{\text{Volume fraction}}$$

$$= 5.33 \cdot (0.5/0.12) = 26.7\ \mathrm{W/cm^3}$$

at a wall loading of 1 $\mathrm{MW/m^2}$.

EFFECTIVE BREEDING RATIO

In addition to the heterogenous corrections discussed above, other corrections are needed to estimate the effective breeding ratio. The individual blanket modules have end caps and inlet/outlet plena, which occupy about 2 and 3% of the module length, respectively. Because the end caps and plena contain no Be, no neutron multiplication occurs. Thus, the local breeding ratio is assumed to be ~ 1.0. Because the breeding ratio calculated with the homogeneous model is 1.93, the end caps and plena are taken to reduce breeding by 0.02 and 0.03, respectively $[(1.93-1.0)\times \text{fractional length}]$. When more detailed design work is undertaken, these corrections should be calculated with a two-dimensional model of the blanket module.

To account for the fusion neutrons that leak from the tandem mirror end cells into the blanket, we take the in-leakage to be equal to the source end-leakage calculated with the two-dimensional blanket model (0.014/source neutron). When these corrections are made the blanket BR is

$$\begin{aligned} BR(\text{Blk}) &\cong [1.93(1-0.06)-(1.93-1)0.05] \\ &\quad \times [1+0.014] \\ &\cong [1.93-0.12-0.05][1.014] = 1.79 \end{aligned}$$

Because D–T fusion also occurs in the end cells, the effective breeding ratio of the reactor is equal to the blanket BR times the fraction of the total fusion neutrons intercepted by the blanket. This fraction is commonly called blanket coverage and, in this case, is the ratio of fusion power in the central cell to total fusion power.

$$\text{Blanket coverage} = P_{\text{f,cc}}/P_{\text{f,total}} = 0.937$$

$$\therefore BR_{(\text{eff})} = 1.79 \cdot 0.937 = 1.67$$

The net BR is the effective BR minus the tritium consumed, or $BR(\text{net}) = 1.67 - 1.02 = 0.65$. The 2% excess tritium consumed per tritium "burned" is to account for tritium decay and other potential losses, which should actually be significantly less than 2%.

SENSITIVITY TO VARIATIONS IN DESIGN PARAMETERS

To arrive at the reference blanket design, we did a number of iterations on earlier design variations. One case was similar to the final reference case, except the Be zone was 35 cm thick and contained 75 vol% Be at 80% density, 15% vol% H_2O, and 10 vol% Al plus 6 vol% ^{6}Li. This case had a TBR of 1.73. Changes in TBR vs design variations for this case are listed below:

Design variations	$\Delta TBR(\%)$
1. Increased Be zone thickness to 45 cm	+3
2. Removed H_2O in Be zone	+8
3. Increased Be density to 90% of theoretical	+5
4. Replaced H_2O by D_2O	+2

If we apply these results to the reference case, the following observations are made:

1. The 40-cm Be zone is thick and may well be reduced 5–10 cm with only a few percentages drop in breeding. An economic tradeoff is needed.
2. The H_2O volume fraction should be made as low as possible pursuant to heat-transfer requirements. The 4 vol% in the reference design meets this objective.
3. Using high-density Be is advantageous. The Be density should be increased to the point where the radiation lifetime starts to affect the economics adversely because of its effect on capacity factor.
4. Using D_2O in place of H_2 does not appear to be worthwhile.

Before the blanket design is frozen, similar but more detailed parametrics are needed to maximize performance.

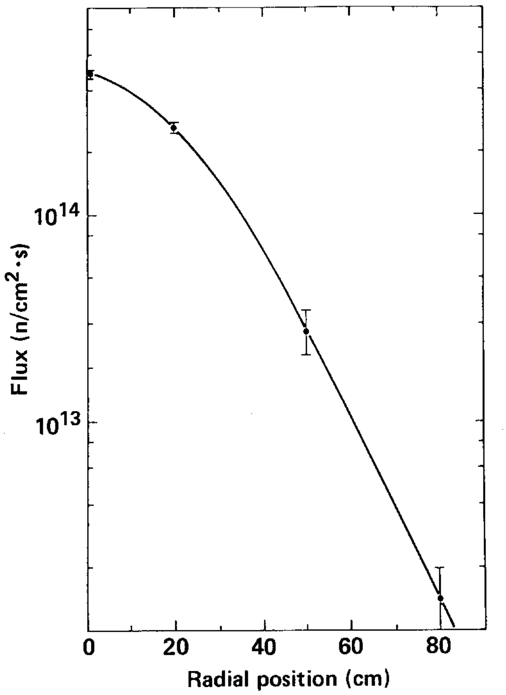


Fig. 3. Neutron flux profile (wall loading = 1.00 MW/m^2).

NEUTRON FLUX AND SPECTRA

At a wall loading of 1 MW/m^2, the current of 14-MeV neutrons through the first wall is 4.43×10^{13} n/cm^2·s. The neutron flux profile and energy spectra in a representative Be blanket with spherical geometry are shown in Figs. 3 and 4.$^{(7)}$ The neutron flux profile in the blanket is nearly exponential. At a wall loading of 1 MW/m^2, the total flux at the first wall is $\sim 5 \times 10^{14}$ cm^{-2}·s^{-1}; at 50 cm into the blanket, the flux has dropped to $\sim 4 \times 10^{13}$ cm^{-2}·s^{-1}. The 14-MeV component of the flux is $\sim 5 \times 10^{13}$ cm^{-2} at the first wall and is down to $\sim 8 \times 10^{10}$·cm^{-2} at 50 cm into the blanket. Although the flux and spectra for our specific blanket must be tabulated, the results should not be significantly different.

MATERIAL EFFECTS

Helium and other transmutation products that build up in the Al structure and Be multiplier blocks are expected to affect the useful life of these components. The Al reactions, reactions per source neutron (S_n), and stable and long-half-life reaction products that occur in the first-wall structure are listed below:

Reaction	No. S_n	Product	
Al(n, 2n)	0.00124	^{26}Al	
Al(n, p)	0.00544	^{27}Al	and H
Al(n, d)	0.00141	^{26}Mg	and H
Al(n, α)	0.00741	^{24}Mg	and He
Al(n, γ)	0.00316	^{28}Si	

At a wall loading of 1 MW/m^2, these reactions and reaction products result in relative production rates

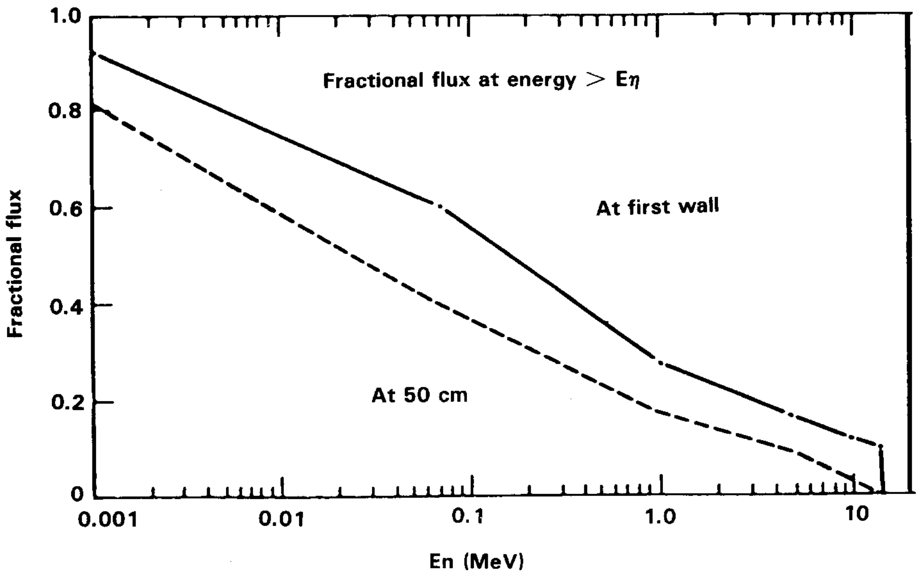


Fig. 4. Neutron flux spectrum.

in the aluminum of

$$\text{Mg:}\quad \frac{0.0088(\text{Mg atoms/n})\cdot 4.43\times 10^{13}(\text{n/cm}^2\cdot\text{s})\cdot 3.15\times 10^{7}(\text{s/y})}{5(\text{cm})\cdot 6.62\times 10^{21}(\text{Al atoms/cm}^3)}$$

$$= 0.0088\cdot 4.22\times 10^{-2} = 3.72\times 10^{-4}(\text{Mg atoms/Al atoms}\cdot\text{yr})$$

$$\text{Si:}\quad 0.0316\cdot 4.22\times 10^{-2} = 1.33\times 10^{-4}(\text{Si atoms/Al atoms}\cdot\text{ yr})$$

$$\text{H:}\quad 0.00741\cdot 422\times 10^{-4} = 3.13\times 10^{-4}(\text{He atoms/Al atoms}\cdot\text{yr})$$

$$\text{He:}\quad 0.00685\cdot 4.22\times 10^{-2} = 2.89\times 10^{-4}(\text{H atoms/Al atoms}\cdot\text{yr})$$

$$^{26}\text{Al}\left(t_{1/2} = 7\times 10^{5}\text{ yr}\right)\text{: } 0.00124\times 4.22\times 10^{-2}$$

$$= 5.23\times 10^{-5}\left(^{26}\text{Al atoms}/^{27}\text{Al atoms}\cdot\text{yr}\right)$$

The transmutation reactions and products of importance in beryllium are in Be(n, 2n) reaction producing two alphas (He) and the α-producing Be(n, α) reaction. In the first 10 cm of the Be zone 0.744 Be(n, 2n) and 0.069 Be(n, α) reactions occur, giving a relative He production rate of

$$\frac{0.813(2)(\text{He atoms/n})\cdot 4.43\times 10^{13}(\text{n/cm}^2\cdot\text{s})\cdot 3.15\times 10^{7}(\text{s/yr})}{10(\text{cm})\cdot 8.93\times 10^{22}\ (\text{Be atoms/cm}^3)}$$

$$= 2.55\times 10^{-3}\left(\frac{\text{He atoms}}{\text{Be atoms}\cdot\text{yr}}\right)$$

A preliminary assessment of the irradiation behavior of Be and Al (given in Ref. 8) suggests that severe radiation hardening and embrittlement of the Al will occur after about 5 years of operation. The Be is not expected to be life-limiting because it is not expected to swell at the temperatures involved. The Be is expected to crack and spall, but the design accounts for this.

PLUTONIUM PRODUCTION MODE

The excess neutrons produced in the blanket can be used to make Pu in place of or in addition to T. Converting this blanket to Pu production has been investigated in a preliminary fashion. The first way considered was to replace the Li–Al slugs in some of the blanket modules with U–Al slugs (30 vol% U and 70 vol% Al). This meant that the remaining modules would still have Li–Al slugs to produce the T needed to fuel the D–T fusion driver, as well as to produce any net T desired. When such a substitution was tried in the cylindrical model, however, it was found to be impractical because too much Pu fission occurred even at the modest Pu concentration (in U) of 0.7 at%. The blanket energy multiplication (M) for this case was 8.6, compared to 1.3 for the TMODE case. To alleviate the problem, only a fraction of the Li–Al fuel was replaced by U (30 vol%) so that the ^{6}Li would suppress the low-energy neutron flux. This worked well because M dropped to 2.4. More detailed analyses will be required to determine if U and Li must be mixed in the same fuel slug or if staggering Li and U slugs is sufficient. A composite slug with Li and Al surrounding the U may prove to be best.

A summary of the nuclear reaction per D–T neutron in the U–Li-containing blanket predicted with the cylindrical model is given below for the case where the U volume fraction of the blanket is 3% and the ratio of Pu to U is 0.7%.

$$^{6}\text{Li}(\text{n,T}) = 0.921$$

$$\text{U}(\text{n},\gamma) = 1.142$$

$$\text{U}(\text{n,fiss}) = 0.042$$

$$\text{Pu}(\text{n},\gamma) = 0.023$$

$$\text{Pu}(\text{n,fiss}) = 0.035$$

$$\therefore T + \text{Pu}_{\text{net}} = 2.00$$

When the same corrections developed for the TMODE case blanket are used here, $T + \text{Pu}_{\text{net}}$(corrected) $= 1.86$. Applying the same blanket coverage factor and tritium requirements gives $BR_{\text{eff}} = 1.74$ and $BR_{\text{net}} = 0.72$.

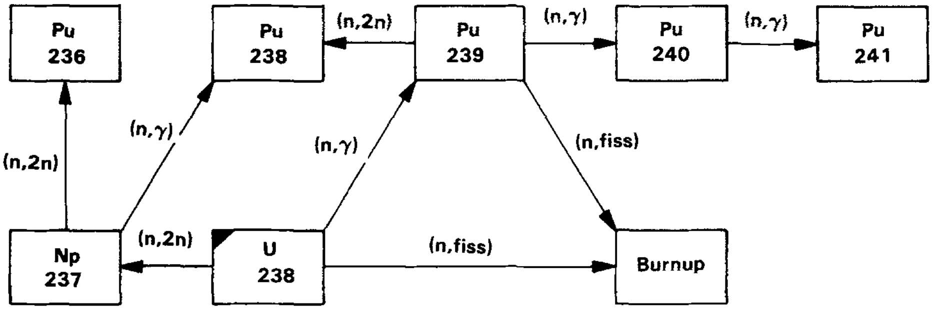


Fig. 5. Actinide chain.

ACTINIDE ISOTOPES

An important aspect of the Pu production mode is the purity of the Pu produced. To estimate Pu and other isotopes of interest, we constructed the activation chain shown in Fig. 5. The half-lives for the intermediate isotopes (e.g., ^{239}U and ^{239}Np) are short and are, therefore, not treated. The reaction probabilities linking elements of the chain were calculated with TARTNP and input to ISOGEN,(9) a mini-version of ORIGEN. Table V shows the results of the calculated Pu composition, as well as burnup (fissioning of heavy metal) and buildup of ^{237}Np, vs exposure (wall loading in megawatts per square meter times the time in years) and position (both inner and outer 10 cm of the 40-cm Be zone).

TOKAMAK BLANKET

A tokamak is also being considered as the fusion driver for the MFPR. The tokamak being considered here is called TORFA. Figure 6 shows schematically a cut perpendicular to its minor axis and reveals the plasma, the blanket, and the components, such as neutral beam ducts and divertor plates, that eliminate or partially shield portions of the blanket. Also shown is the profile of source neutrons emanating from the plasma assumed for this analysis.(10) More-detailed descriptions of the TORFA are given in other papers in this series.(4,11)

To estimate the nuclear breeding performance of the TORFA, we took the local performance calculated for the tandem mirror's blanket and applied it to the TORFA geometry by geometric arguments and approximations discussed below:

1. The fraction of source neutrons interacting with blanket regions that are unencumbered by neutral beam ducts or divertor plates will have the breeding ratio calculated for the tandem mirror blanket without leakage ($T_{\text{local}} = 1.79$). These blanket regions are shown in Fig. 6 as regions 1 (~ 8 to 2 o'clock) and 3 (~ 4 to 5 o'clock).
2. Source neutrons directed out toward the region occupied by neutral beam ducts (region 2, from 2 to 4 o'clock) have the local breeding ratio reduced by twice the fractional geometric coverage of the beam ducts to account for leakage of both secondary and primary source neutrons.

Table V. Plutonium Composition vs Exposure and Position

	At%Pu (inner zone)		At% Pu (outer zone)
Isotope	At 0.158 MWy/m^2 (0.68 at% Pu in U)	At 0.286 MWy/m^2 (1.08 at% Pu in U)	At 2.03 MWy/m^2 (0.974 at% Pu in U)
239	98.9	98.2	98.6
240	1.03	1.6	1.30
241	0.059	0.148	0.088
238	0.042	0.068	0.22
236	1.8×10^{-4}	2.8×10^{-4}	3.1×10^{-5}
(Burnup, % HM)	(0.045)	(0.096)	0.0393)
(^{237}Np in U, %)	(0.0216)	(0.0386)	(0.0111)

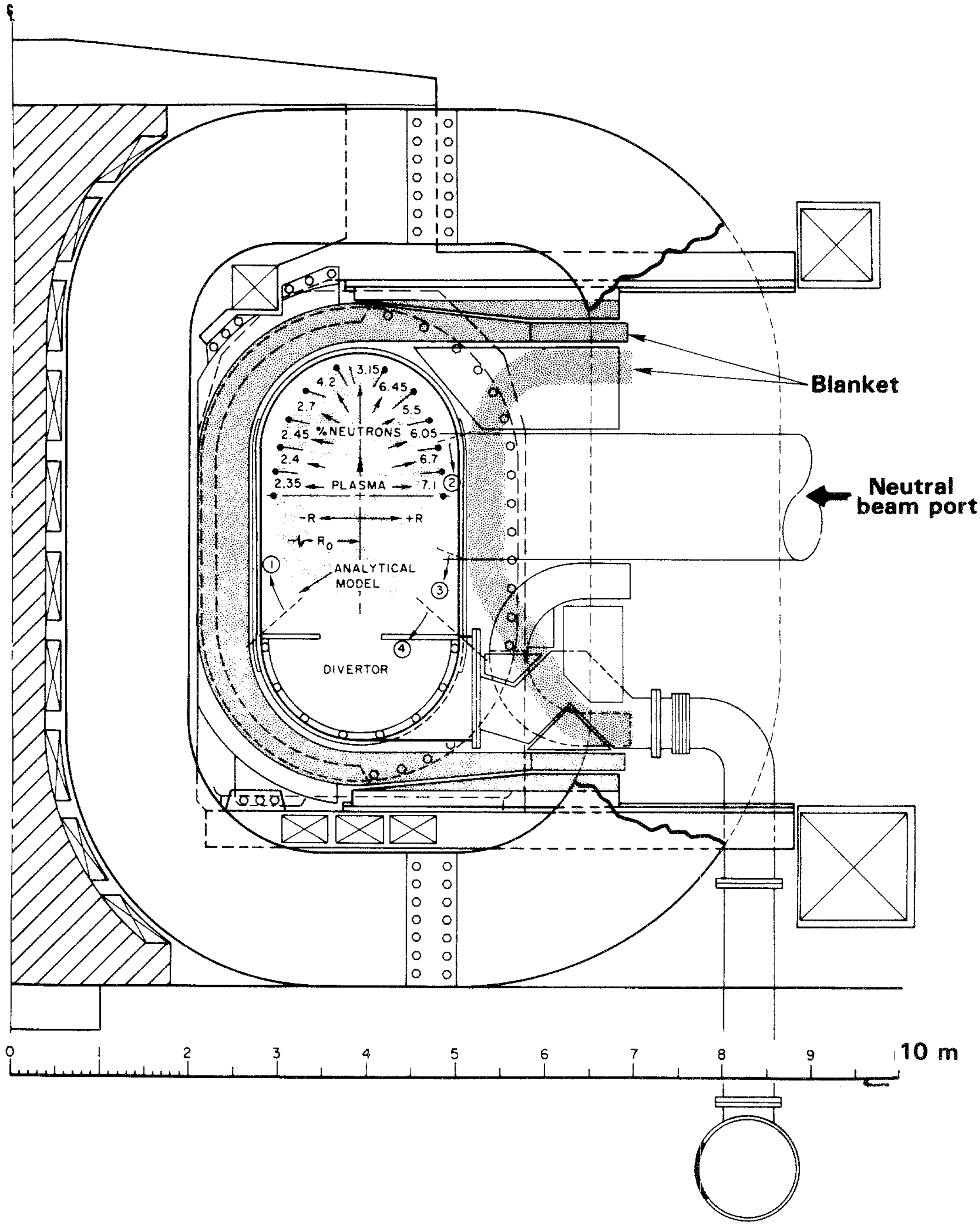


Fig. 6. Schematic drawing of TORFA-type tokamak, cut perpendicular to its minor axis, showing plasma, blankets, and components, such as neutral beam ducts and divertors, that eliminate or shield part of the blanket. Also shown is the profile of source neutrons emanating from the plasma.

3. Source neutrons directed toward the divertor plate (region 8, from 4 to 8 o'clock) are taken to have a local breeding ratio of only 1.0 to account for the effects of the divertor plate.

When the local breeding ratios of these four regions (regions 1, 2, 3, and 8) are combined (Table VI), the resulting effective breeding ratio is 1.49 tritons produced per D-T fusion reactor. This is a recently revised value that departs from the original

Table VI. Effective TORFA Blanket Performance (T'_{eff}) $= \Sigma T_{\text{local}} \cdot f_{\text{n}} \cdot f_{\text{g}}^{a}$

Zone^a	T_{local}	f_{n}	f_{g}	T_{eff}
1	1.79	0.46	1.0	0.823
2	1.79	0.28	0.69	0.346
3	1.79	0.08	1.0	0.143
4	1.0	0.18	1.0	0.180
Total				1.49

$^a T_{\text{local}}$ = local breeding ratio, f_{n} = fraction of source neutrons into zone, and f_{g} = fraction of geometric coverage, modified

$$f_{\text{g}} = \frac{A - AB \times 2}{A} = 1 - \frac{AB \times 2}{A}$$

$$= 1 - \frac{0.8 \times 1.4 \times 2 \times 6}{2\pi \times 5 \times 1.4} = 0.69$$

where AB = beamport area.

one (1.56) used in the companion papers in this issue.[1] To make a more rigorous estimate of breeding in the TORFA geometry, representative three-dimensional models of the TORFA geometry should be developed and analyzed.

SUMMARY

The blanket nuclear design and analysis described herein was done in support of the FY 1982 MFPR study. The tandem mirror case is calculated to have a tritium breeding ratio of 1.67 and an energy multiplication of 1.33. When the reactor is operated in the T-plus-Pu mode, the combined breeding ratio is calculated to be 1.74. Energy multiplication in this mode is a function of Pu content; when calculated with the homogeneous cylindrical shell model, M is 2.4 at 0.7 at% Pu in 3 vol% U. Because of calculational techniques, uncertainties in the calculated breeding ratio are probably in the 5–10% range; nuclear-data-caused uncertainty may be 10%. The tokamak is crudely predicted to have a TMODE breeding ratio of 1.49, with a calculational uncertainty of probably 20%. A rigorous uncertainty analysis, together with more refined calculations, should be undertaken in the next phase of this work.

It is clear that magnetic fusion production reactors can have high breeding ratios. It is also clear that they can be prodigious producers of SNMs, compared to fission reactors of equal power, and that they can do so with no fissile inventory required and with little or no fission occurring.

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