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CORE CONCEPTS FOR "ZERO-SODIUM-VOID-WORTH CORE" IN METAL FUELLED FAST REACTOR

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ABSTRACT

Core design options to reduce the sodium void worth in metal fuelled LMRs are investigated. Two core designs which achieve a zero sodium void worth are analyzed in detail. The first design is a "pancaked" and annular core with enhanced transuranic burning capabilities; the high leakage in this design yields a low breeding ratio and small void worth. The second design is an axially multilayered annular core which is fissile self-sufficient; in this design, the upper and lower core regions are neutronically decoupled for reduced void worth while fissile self-sufficiency is achieved using internal axial blankets plus external radial and axial blanket zones. The neutronic performance characteristics of these low void worth designs are assessed here; their passive safety properties are discussed in a companion paper.

I. INTRODUCTION

Analyses [1,2] and experimental tests [3,4,5] have demonstrated that the physical properties of metallic fuel alloys and the neutronic feedback characteristics of metal-fuelled cores can be exploited to obtain favorable relations among power, power/flow, and inlet temperature coefficients of reactivity; this leads to favorable passive safety response to Anticipated Transient Without Scram (ATWS) initiators. Although large margins between the peak coolant temperature and sodium boiling temperature have been demonstrated for various unprotected transients, there remains a non-zero probability of at least a limited amount of sodium boiling in a metal-fuelled LMR. Several mechanisms have been postulated that can lead to limited voiding (through both boiling and non-boiling mechanisms), including flow blockages, fuel pin failure leading to release of fission product gases that may "blanket" the pins, or cover gas entrain-

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ment and introduction into the core. Moreover, the possibility of large-scale coolant voiding as a result of extremely unlikely events cannot be entirely dismissed; and in current fast reactor designs, large-scale sodium voiding would introduce substantial positive reactivity which could potentially lead to severe reactor damage. In the aftermath of the Chernobyl accident, there has been renewed interest in designing LMR cores with low sodium void worth.[6] For all of the above reasons, there remains a strong incentive to minimize the sodium void worth and the consequent potential for reactor damage in the extremely unlikely event that voiding takes place. Thus, metallic fuelled "zero-sodium-void-worth" core design strategies are developed in Section II.

Recent LMR design analyses [7] have also focused on the design of cores which are net consumers of transuranics. The transuranics dominate the long-term radiological toxicity of spent fuel; thus, it may be desirable to "burn" these transuranic isotopes (commonly called actinide burning, although transuranic burning is more accurate). Metal-fuelled fast reactors offer a number of favorable features regarding management of these man-made actinides. In the pyrochemical processing of the metallic fuel, all transuranics naturally follow the plutonium and are separated from the bulk of the uranium and fission products. Nearly all of the transuranic elements are returned to the core in the closed fuel cycle; thus, the waste streams of the metal fuel reprocessing are virtually free of transuranic elements. In addition, because of the particularly hard neutron spectrum associated with the metallic fuel, actinides are preferentially fissioned, not converted to still higher actinides. The available range of breeding characteristics in metal fuelled cores provides for flexibility in transuranic management strategy. Low breeding ratio designs, combined with repeated recycle can potentially provide for a means to burn transuranics supplied from a source external to the metal fuel cycle (e.g., LWR spent fuel). Alternatively, fissile self-sufficient designs allow a steady-state metal fuel cycle which does not require an external source of fissile material.

A low void worth core design for use in a burner fuel cycle is analyzed in Section III. An alternate low void worth core design for use in a self-sufficient fuel cycle is analyzed in Section IV. Since the margins to sodium boiling or fuel damage in accident situations depend on several reactivity feedbacks as well as on reactor design features and operating conditions, the transient behavior of the proposed designs are evaluated in a companion paper.[8] Both design concepts are at an early developmental stage. The neutronic core performance characteristics have been rigorously scoped out; however, important design areas still need to be evaluated and these activities are currently underway (i.e., steady-state thermalhydraulic performance, reactor stability, vessel commodities, etc.). Thus, the focus of this paper is the neutronics performance of core designs which achieve the goal of a near-zero sodium void worth with the realization that other design issues remain to be resolved.

II. DESIGN OPTIONS FOR REDUCING VOID WORTH

The goal of this study is to analyze design options which reduce the sodium void worth experienced in conventional metal-fuelled, sodium-cooled fast reactors. In this paper, core designs are developed for a 600 MWe core size which achieve a near-zero sodium void worth; metal-fuelled assemblies of conventional geometry and conventional fuel enrichment are utilized. Design strategies for two ranges of breeding ratio are investigated: net burner and fissile self-sufficient.

For the burner core, the design approach is based on application of results given in Ref. 6 where the variation of performance characteristics with void worth was investigated in detail. It was shown that the void worth and the breeding ratio can each be reduced by several methods; substitution of moderator for fuel, geometric spoiling (i.e., core height-to-diameter (H/D) ratio reduction), and high sodium volume fractions. However, of these design options geometric spoiling appears to give the best trade-off between void worth reduction and required increase in enrichment. For a 600 MWe core size, it would be hard to achieve a near-zero void worth with any of the other methods at enrichment levels which are supported by the ongoing IFR fuels irradiation data base program; the plutonium content of prototypic ternary metal fuel is ≤ 28 weight percent Pu/HM.

Geometric spoiling by H/D reduction at constant linear heat rating (pancaking the core) can be achieved using conventional metal fuel assemblies by simply reducing the height of the active driver region and adding additional driver assemblies to the outer core edge. However, for a homogeneous 600 MWe design, this flattening was observed to be limited by the required increases in the fissile enrichment; a near-zero void worth could not be achieved at prototypic (TRU/HM ≤ 28%) enrichment levels. Therefore, core leakage was further increased by adding a central absorber region, creating an annular core design. This annular design eliminates the central power peak; thus, a single driver enrichment can be used (no enrichment zoning) at the upper bound of the enrichment range supported by the ongoing fuels program (e.g., a higher average enrichment is achieved with a lower maximum enrichment). Design studies indicate that a 45 cm tall core with a four row central absorber region yields a zero void worth.

Any high leakage burner core will obviously have a large burnup reactivity swing. Thus, to mitigate the burnup swing penalty, a mid-burn cycle material swap in the annulus is proposed. For the first half of the cycle, absorber assemblies occupy the periphery positions of the central region reducing the core reactivity; at mid-cycle the absorbers are replaced by reflector (steel) assemblies giving a mid-cycle reactivity insertion. It has been found that the absorber exchange is useful only in the outer edge of the central region.

The core designed according to these design strategies is shown in Figure 1. Selected performance and safety characteristics of the proposed burner core design will be discussed in Section III. It should be emphasized that the focus has been on neutronics and passive safety performance; the thermalhydraulics and structural aspects of the design have received only cursory attention. Two principal areas clearly requiring attention are the large diameter of the core (and its impact on structural commodities) and the large coolant ΔT over a very short core (requiring low flow velocities).

For the fissile self-sufficient core having a low void worth, design alternatives were analyzed in a similar manner. Since the geometric spoiling associated with the pancaked core geometry caused a substantial reduction in breeding ratio for the burner core design; significant amounts of fertile material must be added to achieve fissile self-sufficiency. As discussed in Ref. 6, the same physical phenomena which lead to high internal breeding also lead to positive sodium void worth; therefore, to retain a low void worth, external breeding is preferable. Various core designs with the addition of radial, central, and axial blankets to the burner layout were evaluated.[9] For the pancaked core geometry, axial blanket zones are particularly effective because of the dominance of axial leakage; fissile self-sufficiency can be achieved by placement of 30 cm axial blankets above and below the active burner core. However, the presence of an upper axial blanket largely eliminates the negative plenum effect on sodium void worth; the worth for voiding of the active core and upper axial blanket is approximately 1% Δk higher than achieved in the burner core design. Analyses indicated that axial enrichment zoning or further H/D reduction could achieve a near-zero void worth. Alternatively, axially multilayered designs could be utilized. If the internal axial blankets are sufficiently thick, multiple decoupled axial core regions are created; the individual void worths of these small "cores" is significantly less than the void worth of a single large core.

Design teams have extensively analyzed axially heterogeneous layouts in the past.[10,11] In the analysis reported here, double-layered core designs were evaluated; two axial core zones are neutronically decoupled by the presence of a thick blanket/absorber region. Since the two axial "cores" together have the same active volume as the burner design but nearly twice the surface area, a near-zero void worth can be achieved with less geometric spoiling; therefore, the height of each small core was increased and the active core radius was decreased. As shown in Ref. 6 for radially heterogeneous designs, however, penalties in other performance parameters must be incurred when low void worth is achieved by axial decoupling. Compared to conventional core designs, the burnup reactivity swing and fissile enrichment requirements are significantly higher when the core volume is subdivided into decoupled zones; and axial power flattening, a primary attribute of tightly coupled axial heterogeneous designs, is not achieved when the individual core zones are loosely coupled.

The axially decoupled core, which was designed according to the above design strategy, is shown in Figure 2. Selected performance and safety characteristics of this self-sufficient core design are discussed in Section IV. Again it is emphasized that the focus has been on neutronics and passive safety performance; thermalhydraulic and control aspects of the design have received only cursory attention. One principal area requiring attention is the control behavior of the two decoupled core regions which operate at different temperatures.

III. NEUTRONIC ANALYSIS OF THE BURNER CORE

The core layout, shown in Figure 1, consists of 420 driver assemblies and 30 control assemblies in an annular configuration. There is a four row central annulus with the inner three rings steel reflector and the fourth row exchange assemblies. Absorber assemblies are placed in the fourth row at BOC and replaced by reflectors at mid-cycle; this allows some compensation for the reactivity loss independent of the control system and fuel loading. The core is surrounded by one row of steel reflector assemblies and two rows of B_4C shield assemblies. The radial size of the core is large because of the pancaked design (active core height is only 45 cm, while diameter is 355 cm).

In the metal fuel driver assemblies, fuel pins with a 7.5 mm outer diameter are utilized; the assembly lattice pitch is 15.62 cm. The driver pins are close-packed (P/D ratio of 1.18). The duct wall and gap thickness have been sized for the short core active height (low pressure drop). Bond sodium is used within the fuel pins, the high thermal conductivity of the sodium minimizes the temperature drop between fuel and clad. As the fuel expands with irradiation, the bond sodium will be pushed up into the plenum region; the rate and magnitude of bond sodium displacement is expected to vary from pin-to-pin. Thus, for simplicity in the neutronics model, the bond sodium is assumed to have evacuated the active core region (at time zero) and filled the bottom 15 cm of the upper gas plenum. The transuranics in the fresh fuel come from an external feed of reprocessed LWR transuranics and depleted uranium is used as a fertile feed; Each driver assembly has a residence time of three 310 full-power day cycles.

To calculate the neutronic performance of this burner core design, region dependent broad-group cross sections were generated using the *MC²-2*[12] and *SDX*[13] codes. The equilibrium-cycle neutronic performance of the low void worth actinide burner design was analyzed using the *REBUS-3*[14] fuel cycle analysis code. The analysis was carried out in hexagonal-Z geometry using a nodal diffusion approach [15] and 9 group cross section data. Nuclear transmutations for isotopes ranging from U-234 to Cm-246 are modeled. The fuel cycle iteration searches for a fresh transuranic enrichment which maintains criticality throughout the cycle. In the equilibrium model, batch-averaged compositions are used in each depletion region.

The computed equilibrium-cycle performance parameters and isotope mass flows are summarized in Table I. As shown in Table I, the burnup swing is 4.17% Δk and the breeding ratio is 0.53; the burnup swing would be an additional 1.5% Δk larger if the mid-cycle absorber exchange is not utilized. The low breeding ratio makes this core an effective transuranic burner. The fissile consumption rate is nearly twice the fissile production rate; thus, a significant make-up feed of transuranics (containing fissile Pu-239 and Pu-241) is required. One major penalty for this net transuranic consumption is the large burnup reactivity swing; whereas, near-zero burnup swings are achieved in conventional metal fuelled cores where internal breeding is maximized.

Significant design margins are maintained in the assembly irradiation parameters shown in Table I. The driver assemblies have a peak fast fluence of $2.96 \cdot 10^{23} cm^{-2}$ which is well below the design limit of $3.5 \cdot 10^{23} cm^{-2}$. In addition, the peak driver discharge burnup of 118.6 MWd/kg is lower than the conventional limit of 150 MWd/kg. Thus, it may be possible to extend the driver residence time beyond three cycles although additional penalties in reactivity swing and enrichment can be expected.

The power peaking behavior of the low void worth actinide burner core appears to be acceptable. The peak linear power of 495 W/cm (15.1 kW/ft) meets conventional design criteria. The power peaking factor of 1.64 at BOC (which includes the stage factor for fresh fuel) is similar to conventional designs. Note that this power flattening has been achieved without enrichment zoning by introduction of a non-fueled central region. The peak flux and peak fast flux levels are somewhat higher than conventional heterogeneous designs; the homogeneous core region requires a minimal fissile inventory leading to a higher flux level for a given power production. The higher flux levels imply that additional shielding may be required for this design.

The mass flows of Table I show a net consumption of 508 kg/y of heavy metal. Since heavy metal is only consumed by fission, this corresponds to 1.04 g/MWtd, the actinide mass per fission energy factor. Alternatively, the mass flow balance can be viewed in terms of a net loss rather than net consumption. The net loss of TRU isotopes (TRU fission minus TRU production via U-238 capture) is 234 kg/y. The remaining heavy metal loss (274 kg/y) is loss of uranium, predominantly U-238. Thus, the low void worth actinide burner is a net consumer of relatively equal amounts of uranium and transuranics; this corresponds to its breeding ratio near 0.5. Self-sufficient designs (see Section IV) are net consumers of uranium only, and a pure burner core (no U-238) would be a net consumer of transuranics only.

Of the 234 kg/y of TRU losses, 218 kg/y are a net loss of fissile plutonium. This shows that, in the first cycle of residence for reprocessed LWR transuranics, the fissile plutonium is preferentially burned. With repeated recycle, the fissile plutonium contribution would decrease somewhat (hard to transmute transuranics would be present in increasingly higher concentrations) although U-238 capture gives a Pu-239 source each cycle. Thus, some changes in performance can be expected with repeated recycle as the transuranic isotopics gradually shift toward an equilibrium recycle distribution characteristic of this core spectrum and breeding ratio. Preliminary calculations indicate that the void worth increases by nearly $1.0 between the initial core (as analyzed in this report) and equilibrium recycle core.

Whole-core reactivity feedback coefficients were computed for the burner design in its BOC and EOC configurations; results are summarized in Table II. The sodium void worth was calculated using exact perturbation theory, and the sodium density worth (flowing sodium voided without change in cross sections) and the Doppler coefficients for the flooded and voided core were computed using first-order perturbation theory and 21-group cross sections. The radial expansion coefficient, the axial expansion coefficient, and the control rod driveline (CRD) expansion coefficient were determined from differences of eigenvalues computed for perturbed and unperturbed states using 9-group cross sections.

The total void worth quoted in Table II assumes voiding of the flowing sodium in the active core and upper plenum zones. A near zero sodium void and sodium density worth are observed. The void worth is most positive, $0.16, at EOC (as compared to -$0.43 at BOC). Even for this pancaked core, the active core void worth is positive ($2.85 at EOC), but is compensated by a significant negative plenum contribution. This plenum contribution is sensitive to the bond sodium model; the calculated void worth can vary by $1.50 between cases with gas and bond sodium within the pin in the upper plenum. In this analysis, the bond sodium is assumed to fill the bottom 15 cm of the gas plenum.

The Doppler coefficient for this core is quite small. The hard spectrum associated with the high enrichment, high leakage core reduces the Doppler coefficient by reducing the epi-thermal neutron population (where the Doppler self-shielding effect is more important). In addition, the high enrichment leads to a lower concentration of U-238 which reduces the self-shielding effect in U-238. The self-shielding effects in the transuranics isotopes are also minimized by the dispersed transuranic isotopics characteristic of the reprocessed LWR transuranics.

An axial expansion coefficient of -1.50 $/cm is calculated at BOC for fuel expansion. Although this coefficient is slightly larger than conventional designs, the fuel pin length is much shorter (only 45 cm active height); thus, the axial movement for a given temperature change is much smaller and the axial expansion feedback is generally not as effective in pancaked core designs. To the contrary, the radial expansion feedback is enhanced for the same reasons. The calculated value of -1.43 \$/cm at BOC is similar to conventional designs, but the radial movement for a given temperature change is much larger. Thus, radial expansion is a dominant feedback for pancaked core designs because of the dominance of axial leakage. The reduced fuel concentrations associated with a radial expansion allow more axial leakage while the increased radius reduces the much less important radial leakage.

A quite large control rod driveline expansion coefficient of -0.78 \$/cm is calculated at BOC. Although the value of -0.41 \$/cm at EOC (where the rods are not partially inserted) is much smaller, this effect is still 4-8 times larger than that observed in conventional designs. The primary reason for this increase is the large number of control assemblies in this design; thus, a 1 cm insertion introduces proportionally more absorber into the core. In addition, small insertions are more effective in a shorter core. The calculated values of β_{eff} (3.50E-3 at BOC) and the prompt neutron lifetime (2.17E-7 s at BOC) are also given in Table II at BOC and EOC. The passive safety performance of this burner core design is discussed in Ref. 8.

IV. NEUTRONIC ANALYSIS OF A FISSILE SELF-SUFFICIENT CORE

The core layout, shown in Figure 2, consists of 210 driver assemblies, 24 control assemblies, and 192 radial blanket assemblies in an annular configuration. This core design was chosen because of the radial size reduction compared to the pancaked annular burner designs; the active core diameter is 258 cm which is a 97 cm reduction from the burner design shown in Fig. 1. The upper and lower cores are divided by two internal axial blanket zones and an internal absorber region. The thickness of the absorber region has significant effects on void worth reduction and core performance. A zero void worth is achieved for an absorber region thickness of approximately 20 cm with natural boron carbide absorber and 60 cm with natural hafnium absorber; 60% enriched hafnuim-177 is expected to have effect similar to the natural boron carbide.

Metal fuel assemblies similar to the burner design were utilized in this analysis; only the axial zone specifications are modified. In the radial blanket, a fuel volume fraction of 49% was assumed; and a higher fuel smear density of 85% was assumed in all blanket regions. Each driver assembly has a residence time of three cycles of 310 effective full power days each; and the blanket assemblies have a four cycle residence time.

To calculate the neutronic performance of this self-sufficient core design, a 7 group cross section set was processed from the JENDL-3 nuclear data file.[16] The burnup performance was calculated using an R-Z model in a conventional diffusion code; equilibrium cycle performance was evaluated. The computed equilibrium-cycle performance parameters are summarized in Table III.

As shown in Table III, the breeding ratio is 1.07. This breeding ratio facilitates a fissile self-sufficient fuel cycle; the net fissile plutonium gain is 81 kg/year. Since the large increase in breeding ratio arises primarily from external breeding, the burnup swing remains quite large at 5.19 %$\Delta k/kk'$. Because the two core zones are neutronically decoupled axially and each of about half the burner core volume, the fresh fuel fissile enrichment requirement is larger than required in the single zone burner design. The fissile self-sufficient design exhibits assembly irradiation and power peaking performance similar to the burner design. As shown in Table III, the discharge burnup peak linear power, and peak fast fluence levels are similar to the burner design, well below design limits.

Whole-core reactivity feedback coefficients were computed for the self-sufficient design in its EOC configuration; results are summarized in Table III. Because the upper and lower cores regions are neutronically decoupled, their feedback responses are independent. The reactivity coefficients shown in Table III are calculated for a single axial core region; because the geometry of the upper and lower core regions is virtually identical, the reactivity feedback coefficients are applicable to either axial segment of the overall core design. The Doppler coefficient, mass reactivity coefficients (for fuel, sodium, and steel in each region), and geometry coefficients (axial active core expansion and uniform radial expansion with constant material densities) were computed using an R-Z model of the upper core region and 25-group cross sections. The axial and radial feedback coefficients were calculated by combining the geometric and mass reactivity coefficients. The control rod worths were evaluated in a similar manner with adjustment factors to account for three-dimensional effects.

Near zero sodium void and sodium density worths are observed. Although the active core void worth is positive ($1.7 at EOC), it is compensated by significant negative contributions from voiding of the internal and axial blankets. Similar to the burner design, the Doppler coefficient is quite small because of the high enrichment and hard spectrum in the fueled zones. However, the blanket regions can give a significant Doppler effect which is not present in the burner design. Because the axial flux gradients and number of control rods are similar for the fissile self-sufficient and burner designs, the control rod driveline expansion coefficients are similar and much larger than for conventional LMR designs.

The axial expansion coefficient of -1.72 $/cm is much larger than the burner design; and the radial expansion coefficient of -2.54 $/cm is also larger. The larger geometric expansion coefficients are caused by two effects. Since the individual core zones of the self-sufficient design are roughly half the volume of the burner core and the enrichment is correspondingly larger, a harder neutron spectrum is observed in the self-sufficient design; since fast neutrons have a higher leakage probability, leakage effects (which cause the expansion reactivity feedback) will be more prominent in the smaller core. In addition, the self-sufficient design has a smaller core radius; this leads to an increase in radial leakage which enhances the axial expansion coefficient.

V. SUMMARY

Two 600 MWe cores, a pancaked annular burner core and a fissile self-sufficient axially decoupled annular core both designed to reduce the sodium void worth in metal fuelled LMRs, were evaluated. For each core, the equilibrium-cycle neutronic performance was evaluated; and the reactivity feedback coefficients were calculated. Both cores achieved the design goal of this study, a near-zero sodium void worth which was the major focus of this paper.

For the burner core, a low breeding ratio of 0.53 is achieved indicating an effective transuranic burner; a net consumption of 234 kg/y of transuranics is calculated for the 600 MWe power rating. Because of the high leakage, a large burnup reactivity swing is observed. The power peaking and assembly irradiation characteristics appear to be similar to conventional designs, The calculated value of the sodium void worth at EOC is $0.16; this value includes the negative contribution from voiding of the upper plenum region in the driver assemblies. Because of the high enrichment, the Doppler coefficient is significantly smaller than in conventional designs. However, the radial expansion and control rod driveline expansion coefficients are significantly enhanced by the flat, annular layout.

For the fissile self-sufficient core, an axially multilayered annular core design was evaluated; a zero sodium void worth is achieved with a breeding ratio of 1.07. The net fissile plutonium gain is 81 kg/y at the 600 MWe power rating. The radial core size is substantially reduced compared to the flat annular burner design, and appears to be similar to conventional designs of similar power rating. The power peaking, assembly irradiation characteristics, and reactivity coefficients are quite similar to the burner design. The passive safety performance of such cores is evaluated in Ref. 8.

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Table I. Equilibrium-Cycle Performance Parameters

Breeding Ratio	0.533
Burnup Swing, %Δk	4.17[a]
Average Discharge Burnup	
MWd/kg	82.6
Atom %	8.8
Peak Discharge Burnup	
MWd/kg	118.6
Atom %	12.6
Peak Linear Power[b], W/cm	
BOC	495
EOC	462
Power Peaking Factor[b]	
BOC	1.64
EOC	1.53
Peak Flux, $10^{15} cm^{-2} s^{-1}$	
BOC	4.84
EOC	5.02
Peak Fast Flux, $10^{15} cm^{-2} s^{-1}$	
BOC	3.68
EOC	3.77
Peak Fast Fluence, $10^{23} cm^{-2}$	2.96
Mass Flow, kg/y	
Heavy Metal	5,790
Transuranics	1,492
Fissile Pu	958
Net Loss, kg/y	
Heavy Metal	508
Transuranics	234
Fissile Pu	218

[a] Absorbers in outer row of annulus are exchanged for reflectors at mid-cycle; without exchange, burnup swing is about 5.5% Δk.

[b] Includes batch effect by using stage factors for fresh fuel assemblies.

Table II. Low Void Worth Actinide Burner Reactivity Coefficients

	BOEC[a]	EOEC
Sodium Void Worth, $		
Core	1.78	2.85
Plenum	-2.20	-2.70
Total	-0.43	0.16
Sodium Density Worth, $		
Core	1.54	2.57
Plenum	-1.78	-2.16
Total	-0.24	0.41
Fuel Doppler Coefficient, $-10^{-3}T\ dk/dT$		
Flooded		
Fuel	0.73	0.88
Structure[b]	0.30	0.35
Voided		
Fuel	0.36	0.46
Structure[b]	0.21	0.25
Axial Expansion Coefficient, $/cm		
Fuel	-1.50	-1.19
Fuel and Structure[b]	-1.37	-1.01
Radial Expansion Coefficient, $/cm	-1.43	-1.48
Control Rod Driveline Expansion Coefficient, $/cm	-0.778	-0.414
Beta Effective	3.50E-3	3.47E-3
Prompt Neutron Lifetime, s	2.17E-7	2.47E-7

[a]BOEC values are calculated for critical configuration, with primary rods inserted 24 cm.

[b]Values reflect perturbation of total structure; clad effects can be estimated as 63% (volume fraction of clad in the total structure) of the total structure effect.

Table III. Equilibrium-cycle Performance Parameters for Low Sodium Void Worth Fissile Self-Sufficient Core

Plutonium Enrichment	28.0%
Breeding Ratio	1.07
Burnup Swing, % ΔK	5.19
Average Discharge Burnup	
MWd/kg	72.1
atom%	7.7
Peak Linear Power, w/cm	
BOC	477
EOC	413
Peak Fast Fluence 10^{23} cm^{-2}	2.6
Mass Flow, kg/y	
Fissile Pu	1090
Net Gain , kg/y	
Fissile Pu	81
Sodium Void Worth, \$, (EOC)	
Whole Core	0.
Active Core	1.7
Sodium Density Worth, \$, (EOC)	
Whole Core	-0.31
Active Core	1.8
Fuel Doppler Coefficient, $-10^{-3}T$ dk/dT	
Flooded (EOC; Fuel and Structure)	
Core	1.69
Axial Blanket	0.41
Radial Blanket	0.37
Axial Expansion Coefficient, \$/cm	-1.72
Radial Expansion Coefficient, \$/cm	-2.54
Control Rod Driveline	
Expansion Coefficient, \$/cm	
BOC	-0.69
EOC	-0.43

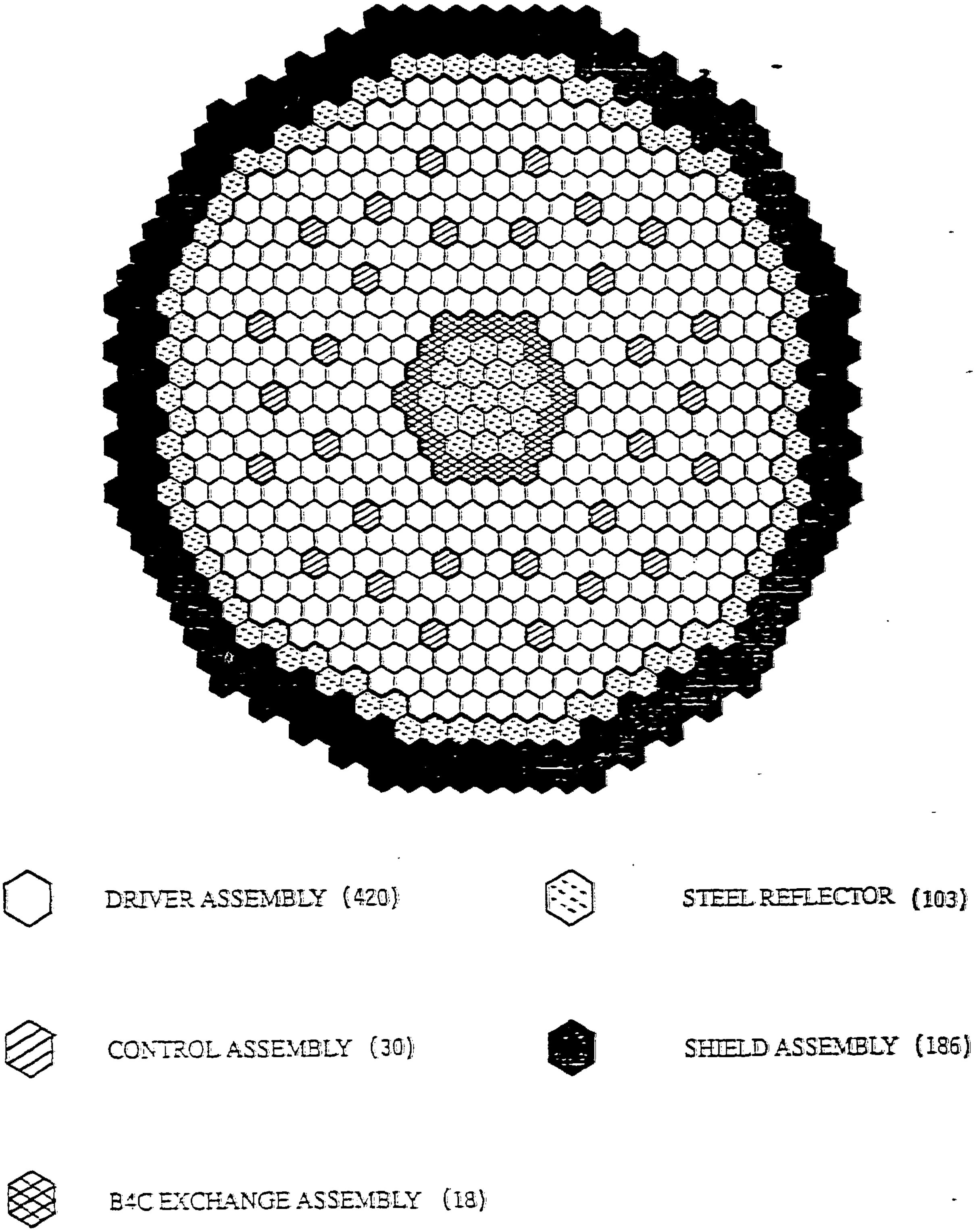

Figure 1. Low Void Worth Actinide Burner Core Layout

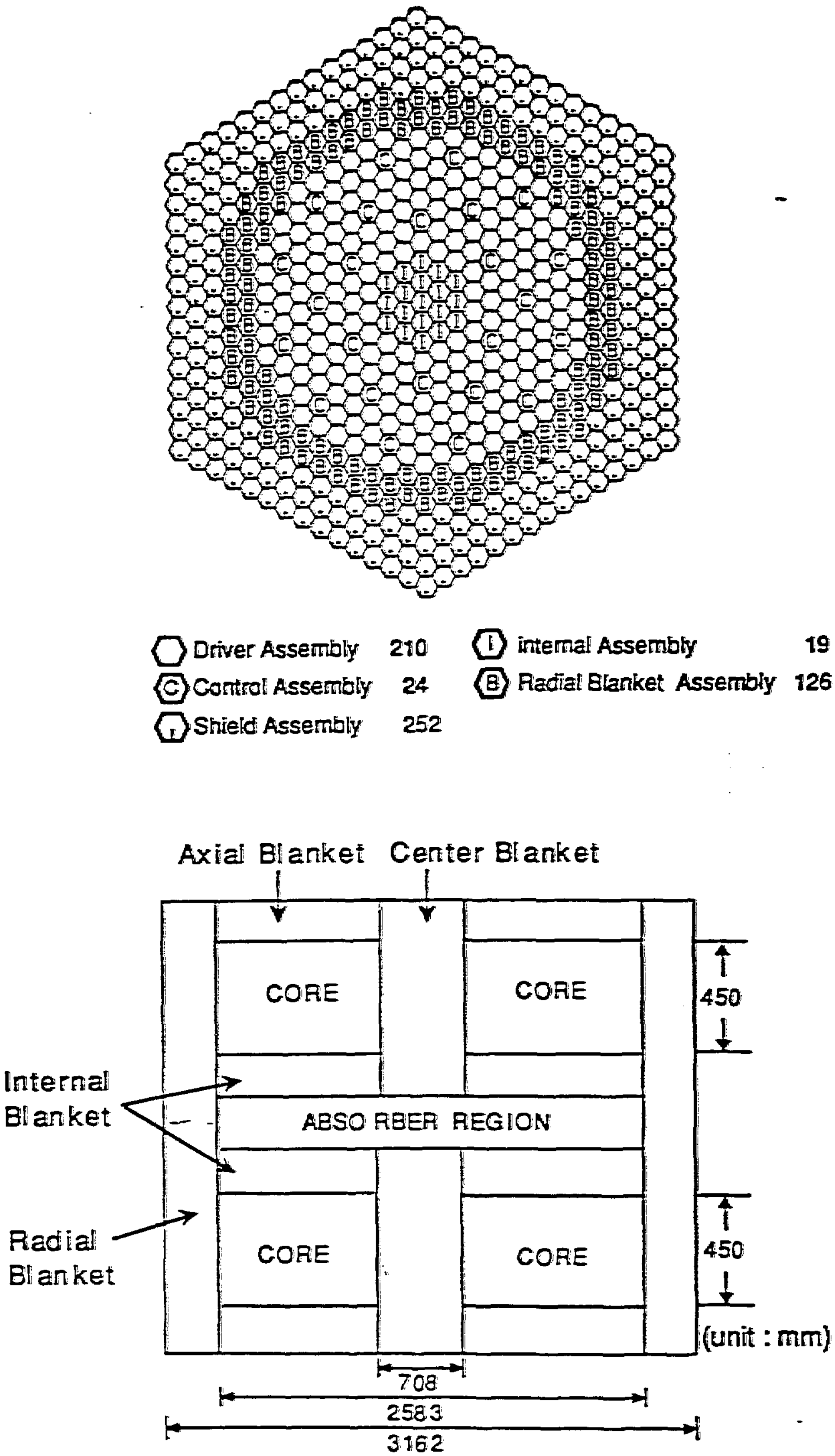

Figure 2. Low Sodium Void Worth Fissile Self-Sufficient Core Layout