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BREEDING RATIO AND DOUBLING TIME CHARACTERISTICS OF THE CLINCH RIVER BREEDER REACTOR

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ABSTRACT

MASTER

The Clinch River Breeder Reactor, per the current design, will have a breeding ratio of 1.20 at the start-of-life and 1.23 at the end of the first cycle. This value is expected to drop to approximately 1.12 in the equilibrium cycles if the present type fuel and blanket assembly designs are retained. However, with reasonably anticipated advances in fuel design technology, a breeding ratio of at least 1.20 can be maintained throughout the life of the plant. Potential equilibrium fuel assembly designs have been proposed which will accomplish this objective as well as achieve the design goal burnup of 150,000 MWd/T. CRBR, with a peak linear power rating of 14.5kW/ft and an equilibrium breeding ratio of 1.20, has a compound system doubling time of approximately 34 years.

1. INTRODUCTION

A design goal of the Clinch River Breeder Reactor (CRBR) is the demonstration of a breeding ratio not less than 1.20. The Clinch River plant must, in addition, demonstrate the potential for economically competitive power generation. Therefore, optimization of nuclear performance parameters must be carefully integrated with its impact on fuel cycle costs. In order to assure a high degree of reliability, safety and ready licensability, design trade-offs are required which, in some cases, are contraproductive to maximum breeding performance. The design philosophy in the Clinch River plant has been to guarantee the basic design-guideline breeding ratio but to initially apply any additional nuclear capability in the area of minimizing fuel cycle costs which are directly reflected in the economic desirability of LMFBR power systems. In the paragraphs that follow, the breeding and doubling time characteristics of CRBR will be discussed as per the design at the time of submittal of the PSAR (Fall, 1974), as well as the anticipated trends in breeding capability in the equilibrium cycles. Expected areas for improved breeding performance will be highlighted and fuel design concepts will be presented which will maintain the desired level of breeding performance throughout the life of the plant.

The reference CRBR design is discussed at some length in other papers in these transactions (1). Table I is a summary of the design parameters which are pertinent to the breeding and doubling time performance characteristics

of CRBR.

2. BREEDING RATIO

The definition of breeding ratio is the point in time rate of production of fissile isotopes divided by the rate of destruction of fissile isotopes. Fissile isotopes include Pu^{239} , Pu^{241} and the amount of U^{235} in excess of that found in depleted uranium (0.2%). The amount of U^{235} up to and including that found in depleted uranium is not included as a fissile material insofar as it is not economically feasible to extract it as a reactor fuel from the ore. Fissile production and destruction rates (fertile capture rates and fissile absorption rates, respectively) are calculated from cycle depletion analyses of explicit first and equilibrium core reactor models with the 2DB (2) code and ENDF/B-III data. The sensitivity of the breeding ratio to cross sections and related nuclear data is discussed in other papers in these transactions and is not treated as an explicit parameter here.

The referenced CRBR design has a breeding ratio of 1.20 at the start of the first cycle, of which 50% is core conversion, 32% is attributable to the radial blankets and the remaining 18% occurs in the upper and lower axial blankets. Over the course of the first cycle (128 full-power-days), the breeding ratio rises to 1.23 as the control rods are withdrawn and fuel is burned out of the core, causing the flux, and hence the breeding ratio, to rise.

The breeding ratio is sensitive to a number of CRBR design parameters. In particular, the plutonium fuel is assumed to be derived from a mixture of discharge batches from currently operating light water reactor plants with an average isotopic composition as stated in Table I. This so called "dirty" plutonium contains a significant percentage of fertile Pu^{240} and, especially, high-reactivity-worth Pu^{241} . If this same first core were loaded with "clean", FFTF-grade (3), plutonium fuel*, the required fissile loading to obtain the same start-of-cycle excess reactivity would be approximately 8% higher, and the resulting breeding ratio nearly .06 lower than the reference design. The drop in breeding ratio is attributable to the lower fertile material content in the clean plutonium core. This breeding ratio behavior serves as strong incentive to strive to recycle the available LWR discharge plutonium fuel through LMFBR plants in spite of the fabrication difficulties due to inherently higher levels of radioactivity. Similarly, if this same core were fueled with recycled LMFBR discharge core plutonium, the breeding ratio might be expected to increase of the order of .01 to .02 as a result of the higher fertile material content in the heavier plutonium isotopes. A typical LMFBR discharge batch, however, will contain some fraction of radial and axial blankets so that the plutonium isotopic content of the mixture of fuel and blankets is expected to be very similar to that obtained from the LWR discharge fuel. Hence, no pronounced changes in breeding capability (from feed fuel isotopic content variations) are anticipated if recycled LMFBR fuel is employed, in place of LWR recycle plutonium, as feed material in the later cycles in CRBR.

The planned operating philosophy for CRBR is based on yearly refueling intervals, initially at a full power capacity factor of 0.35 (128 equivalent-

*86.4% Pu^{239} , 11.7% Pu^{240} , 1.7% Pu^{241} and 0.2% Pu^{242} .

full-power-days) for the first cycle, 0.55 (200 equivalent-full-power-days) in the second cycle and subsequently at a full power capacity factor of 0.75 (274 equivalent-full-power-days) in the equilibrium cycles. The transition from the first to the equilibrium cycles and the assumed development of fuels with high peak burnup capability (150,000 Mwd/T in the equilibrium cores) are discussed in another paper in this session (4). The average fuel burnup (100,000 Mwd/T in the equilibrium cycles), the fuel and blanket assembly residence times (3 and 6 years, respectively) and the refueling interval (annual) are important parameters in determining the breeding characteristics of CRBR. High average fuel burnups lead to large fission product inventories. Long fuel assembly residence times and long refueling intervals require relatively high enrichments in the feed assemblies in order to maintain the reactivity balance throughout each cycle. In addition, long refueling intervals require substantial inserted start-of-cycle control worth which competes directly with the fertile materials for parasitic capture of excess neutrons. All of these effects are contraproductive to maximum breeding efficiency, but they contribute to lower fuel cycle costs by maximizing the lifetime and average burnup of the fuel assemblies (within the limitations of safety and reliability of the pellet, clad and structural materials), and by increasing the plant availability by reducing the required down-time for refueling per year. Long radial blanket assembly residence times lower the capital costs incurred from the assembly inventory required over the lifetime of the plant, but again at the expense of optimum breeding efficiency insofar as some fraction of the bred plutonium in the blankets is burned out in a relatively low reactivity worth region prior to discharge.

In the progression from the first to the equilibrium cycles, if one assumes that the appropriately enriched first-core-design fuel and blanket assemblies are retained, the breeding ratio would be expected to fall to approximately 1.12. This drop in breeding capability is attributable to a combination of higher required plutonium enrichments in order to sustain the longer cycles and higher discharge burnups, the buildup in the fission product inventory, the depletion in the average U^{238} content and the flux and worth redistribution resulting from radial and axial blanket plutonium buildup. Table II lists a number of potential areas where the equilibrium breeding characteristics of CRBR can be improved in order to maintain the breeding ratio at or above the 1.20 level. All of the incremental improvements in Table II cannot necessarily be accumulated simultaneously and some cannot be achieved once the final design is frozen. Carbide fuel is not currently considered as a real possibility for use in CRBR, at least in the early cycles, due to lengthy testing and qualification requirements. Carbide blankets are included in Table II to serve as an indicator of the potential improvement realizable from the lower inherent parasitic capture characteristics, and the higher heavy metal content in carbide systems (5).

A number of the changes in Table II (particularly the reduction in the peak fuel burnup limit, the change to semi-annual refueling, the addition of an extra row of radial blanket assemblies or the reduction in the blanket residence time) could adversely affect fuel cycle costs and are therefore not particularly promising candidates. The single-zone-enrichment core concept, although it improves the breeding ratio and slightly lowers the fissile mass requirements, is not considered as viable due to the unacceptably high power peaking factors near the center of the core. Some breeding improvements are expected to evolve naturally as experience gained in the early cycles is applied to the reactivity and control requirements to enable the

feed fuel enrichments and control margins to be lowered. A reduction in control scram dynamics uncertainties may eventually allow the parked safety control rods to be withdrawn a few inches back into the upper axial blanket, reducing the parasitic neutron capture in the parked rods and increasing the breeding contribution from the upper axial blanket (which currently breeds only approximately 60% as much as the lower axial blanket. However, this change would have to be incorporated before the final plant design is frozen in order to be compatible with the available control rod travel. Current estimates of the Pu^{238} content in high burnup LWR discharge plutonium range from zero to 1 or 1.5%. When Pu^{238} is included as a fertile material, the breeding ratio increases of the order of 1.5% per % Pu^{238} . However, insofar as the exact Pu^{238} content in the LWR discharge plutonium available for CRBR feed material is uncertain at this time, no specific credit is being taken for this increased breeding capability.

A positive approach to assure that the equilibrium breeding ratio is maintained at the 1.20 level lies in the category of feed fuel and blanket assembly modifications which will allow the fertile material loading in the reactor to be increased. The proposed changes have been limited to those which do not involve core or blanket layout changes (i.e. control and fuel assembly interchanges or fuel and blanket assembly interchanges are not considered since they would impact, among others, the reactor flow allocation) and ones which can be made within the same subassembly volume to permit the new assemblies to be installed as reload batch cores in the later cycles. Sensitivity studies at a constant reactivity state were performed in the first core to produce the following set of first-order perturbation coefficients relating the change in breeding ratio to changes in the pellet, steel (clad plus structure) and sodium volume fractions:

$$\frac{\Delta \text{BR}}{\Delta \text{ Pellet}} = +1.4,$$

$$\frac{\Delta \text{BR}}{\Delta \text{ Steel}} = -0.2,$$

$$\frac{\Delta \text{BR}}{\Delta \text{ Sodium}} \text{ less than } -0.05.$$

Hence, it is apparent that the breeding ratio is primarily affected by changes in the pellet volume fraction and only to a much lesser extent by changes in the steel and sodium content. This set of coefficients is used in design feasibility studies to scope the expected change in breeding ratio associated with any proposed fuel or blanket design change. Full scale nuclear design analyses are carried out on potentially promising design concepts to access the total nuclear performance impact.

In addition to the usual safety and economic bounds, the range of viable fuel assembly design modifications is further limited by mechanical and thermal hydraulic constraints. The fuel pellet diameter can be increased by trimming the cladding thickness from 15 to 10-12 mils (and retaining the fuel rod

O.D. and the pellet/clad gap), although the associated increase in breeding ratio is achieved at the expense of a 1 year reduction in fuel lifetime capability (cladding strength limitation) or alternately a reduction in reactor outlet temperature of nearly 100°F which penalizes reactor efficiency. However, a reduction in clad thickness, and the associated lifetime penalty, may be acceptable in the early cycles where the fuel assemblies are already lifetime limited (stainless steel swelling). A reduction in the required pellet/clad diametral gap from 6.5 to 4.5 mils would allow a larger diameter fuel pellet to be incorporated in the same fuel rods. However, the cost penalty associated with grinding the fuel pellets to the required tolerances make this option less attractive. Since high-density fuel pellets are commercially fabricated for LWR's, an increase in the pellet fabrication density from 91.3 to 95% of theoretical density seems feasible. The maximum fuel rod O.D. is limited by the available area within each subassembly duct. In addition, the fuel rod pitch-to-diameter ratio must be set such that the coolant pressure drop across the core does not exceed the available pump head for a given coolant temperature rise. Currently the available pump head limits the maximum reactor pressure drop to about 120 PSI (reactor vessel nozzle-to-nozzle) with a 265°F coolant temperature rise. If the coolant temperature rise were allowed to increase, then the fuel rod diameter (and hence the breeding ratio) could be increased accordingly with the same pump pressure head, although again at the expense of reduced fuel lifetime (high temperature clad strength limitation). In the long run, one would like to open up more space within the fuel assemblies by reducing the 95 mil inter-assembly gap (for thermal and radiation-induced duct swelling and/or bowing) and the 120 mil duct thickness to allow larger diameter fuel rods to be installed in the assemblies without affecting either the coolant pressure drop or the coolant temperature rise (lifetime). These modifications require the development of a new high-strength, low-swelling duct material alloy, such as a high-nickel steel of the A286-* or PE16-type. Indications are that such a high-strength, low-swelling alloy is already required for the cladding and duct materials in order to be compatible with the high neutron fluences associated with a design goal of 150,000 Mwd/T peak burn-up capability in the equilibrium cycles.

Table III compares the characteristics of a proposed equilibrium feed fuel assembly design for CRBR with those of the first-core, FFTF-type assemblies. This design is the result of an interdisciplinary feasibility study involving an assessment of nuclear, mechanical, thermal/hydraulic and plant performance objectives. The recommended equilibrium assembly design utilizes a new high-strength, low-swelling duct (and perhaps clad) material which permits a larger fuel rod O.D. to be incorporated without affecting the coolant pressure drop across the core (and hence the available pump head), the design coolant temperature rise in the reactor (hence the reactor outlet temperature or the secondary steam-side of the plant) or the clad thickness (lifetime). Irradiation test programs are being initiated at this time in order to qualify the new materials for compatibility with the neutron fluences associated with a peak design-goal burnup of 150,000 Mwd/T. The combined effects of larger pellet diameter, lower steel content and higher pellet density in the core result in an equilibrium (cycle-average) breeding ratio of 1.22 with the proposed fuel and radial blanket assembly modifications.

* The approximate composition of A286 is 55 w/o Fe, 26 w/o Ni, 15 w/o Cr, 1.3 w/o Mo and 1.4 w/o Mn plus trace impurities compared to 316-SS which contains 64 w/o Fe, 13.5 w/o Ni, 17.5 w/o Cr, 2.5 w/o Mo and 1.8 w/o Mn plus impurities.

Depending on the outcome of the irradiation test program and the concurrent availability of the new feed assemblies with the approach to equilibrium conditions, an interim design is included in Table III which will maintain the desired 1.20 breeding ratio. The interim design retains the 20% CW 316-SS duct and clad (and therefore it is not tied to the material development program) and achieves its improved breeding characteristics at the expense of a reduced assembly lifetime (2 vs. 3 years) and a lower peak burnup capability (80,000 vs. 150,000 MWd/T) from a reduction in clad thickness.

It is apparent that the design goal breeding ratio of 1.20 or greater can be maintained throughout the equilibrium cycles in CRBR without overly optimistic assumptions on the progress in fuel and blanket assembly design technology. Additionally some margin exists for "fine tuning" the breeding ratio with other combinations of the options in Table II. It is important to realize that, whereas the breeding ratio is a convenient measure of the nuclear "efficiency" of the Clinch River reactor, it does not tell the whole story. A significant design consideration in satisfying the economic objectives of the LMFBR is the mass of fissile material produced over a period of time, or the net fissile mass gain which is related to the doubling time.

3. DOUBLING TIME

Doubling time is a measure of the rate of production of excess fissile material in a breeder reactor system and; as such, it is a more important parameter in terms of the establishment of an economically viable and expanding electric economy than is the breeding ratio alone. A number of variations exist in the definition of doubling time depending on the treatment of the plutonium inventory tied up in fabrication and reprocessing which is assigned by proration to a given fuel cycle investment, the treatment of fissile material losses in this same fabrication and reprocessing cycle, and whether or not the bred plutonium is assumed to be continuously reinvested which subjects the doubling time to compounding. In general, simple schemes for predicting doubling time based on global physics parameters (α , specific power, breeding gain, etc.) are unreliable due to inherent difficulties in obtaining the proper global spectrum-, space- and time-dependent physics constants throughout a fuel cycle without an explicit depletion analysis. If the explicit depletion analysis is available, then it is more straightforward to deduce the doubling time characteristics from the mass inventories. The difficulties in predicting equilibrium cycle nuclear characteristics (and hence doubling time) based on first cycle physics parameters has been discussed by Adkins (6). In CRBR, the doubling time characteristics have been deduced from the start- and end-of-cycle fissile mass inventories obtained from explicit equilibrium depletion analyses, which reflect the behavior of the aforementioned physics parameters directly.

The doubling time in CRBR, including compounding, system inventory and fissile losses, is given by

$$DT(\text{yr}) = \frac{\ln 2 * \text{Fissile Mass}}{[\text{Fissile Mass Gain/Cycle} - \text{Fissile Mass Losses/Cycle}] * \text{Cycles/Year}}$$

where

Fissile Mass is the total system fissile plutonium inventory which consists of one full equilibrium core load in the reactor plus one reload (1/3 core) tied up in the cooling-reprocessing-fabrication cycle,

Fissile Gain/Cycle, related to the breeding gain and the specific power, is obtained from the mass inventories in a cycle depletion analysis,

and

Fissile Mass Losses/Cycle are the fissile plutonium losses in fabrication and reprocessing, assumed to be 1% of the fissile inventory in each reload batch, plus the Pu^{241} -decay losses.

The system fissile mass inventory includes the full equilibrium-cycle core fissile plutonium loading (doubling of the start-of-life fissile loading in CRBR is not particularly meaningful due to the initial low "demonstration" cycle capacity factors). The equilibrium bred fissile plutonium inventory in the radial and axial blankets is not included in the reactor inventory since it is not necessary to double this particular mass in order to build and operate another identical plant in the same reactivity state. That is to say, due to the low reactivity worth of the plutonium in the blankets, one would obviously not choose to load the fresh plant with plutonium in the blankets. The progression of the plutonium inventory external to the plant in the fabrication and reprocessing cycles is beyond the control of the nuclear designer, and can cloud the interpretation of doubling time as a measure of reactor nuclear efficiency. However, meaningful minimum system inventories can be defined by balancing the mass flow into and out-of the plant. In CRBR, with 1/3 of the core fuel assemblies refueled annually, one must assume, at a minimum, that one reload batch must be discharged from the reactor, cooled, reprocessed, and subsequently refabricated into feed assemblies each cycle in order for the "system" to be in equilibrium. Therefore, for this analysis, the plutonium inventory tied-up in the reprocessing/fabrication cycle is assumed to consist of 1/3 of an equilibrium core load per cycle (i.e. one reload batch) so that the system "investment" is 1-1/3 equilibrium cores.

The net fissile mass gain per cycle is related directly to the breeding gain and to the reactor specific power (MW/kg fissile, or the linear power rating at constant geometry which is proportional to the fissile destruction rate, and hence to the fissile production rate at a constant breeding ratio). In CRBR, the net fissile plutonium gain per cycle is determined from the start- and end-of-cycle mass inventories from an explicit equilibrium cycle depletion analysis.

The fissile losses per cycle are assumed to consist of 1% of the total fissile plutonium mass processed through reprocessing and fabrication during each fuel cycle. In equilibrium, this represents a loss of 1% of each reload batch (1/3 core plus 1/6 radial blanket) per cycle. The system fissile losses also include the decay of Pu^{241} in the reactor inventory and in the reprocessing-fabrication batch outside the reactor.

In an expanding network of reactors, where there is immediate demand for - and hence nearly instantaneous reuse of - bred plutonium, the compound doubling time is appropriate. These conditions are not truly ful-

filled for a single reactor like CRBR, especially in the early demonstration cycles. However, some compounding occurs as the bred plutonium "soaks" in the assemblies prior to discharge, and also as reprocessed fuel is subsequently recycled through the Clinch River plant or ultimately into the first-generation LMFBR power plants. The compound system doubling time is the proper indicator of the potential growth rate of an LMFBR-based electric economy, and as such it is the doubling parameter quoted for CRBR although it is understood that this value is not perfectly realizable.

Figure 1 is a plot of the compound system doubling time associated with a particular breeding ratio as a function of the linear power rating of the fuel. The effect of assumed fabrication-reprocessing loss fractions, also shown in Figure 1, is particularly important at low linear power ratings with low breeding ratios where the excess fissile mass gain is relatively small. The behavior of the doubling time with linear power has been treated as though the integrated energy output per cycle (i.e. the burnup) were held constant so that an increase in linear power is reflected in a decrease in cycle length. In this way, the reactor fuel loading, control requirements, etc. are held constant (therefore, to a first order, the breeding ratio is constant), but the cycles/year varies (including the nonlinearity due to the fixed down-time per cycle for refueling). Alternately, the cycle length could have been fixed - at annual refueling intervals - and the required start-of-cycle excess reactivity (fuel loadings), control requirements, etc. allowed to vary with linear power. The change in linear power rating, however, only minimally affects the required fuel loadings since roughly only 10% of the fuel in CRBR is provided for burnup, the remainder being required in order to achieve a fast-critical configuration (which is approximately invariant to power level changes so long as the geometry of the system is unchanged). Either of these treatments produces approximately the same doubling time behavior with linear power.

From Figure 1, CRBR with a conservative linear power rating of 14 kW/ft, and an equilibrium breeding ratio of 1.20, will double in approximately 34 years. A reduction in design uncertainties, based on early-cycle operating experience, which could allow the plant to be operated in a 15% design over-power condition, would enable the system fissile inventory to double in 29 years with the minimum 1.20 breeding ratio, or 25 years with the expected 1.224 equilibrium breeding ratio.

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TABLE I

CRBR DESIGN PARAMETERS RELEVANT TO BREEDING AND
DOUBLING CHARACTERISTICS

CORE DESCRIPTION:

Equivalent Diameter (In.)	73.63
Fuel Height (In.)	36.0
H/D	0.489
No. Of Fuel Assemblies, IC/OC	108/90
No. Of Fuel Rods Per Assembly	217
Fuel Rod O.D. (In.)	0.230
Fuel Pellet O.D. (In.)	0.1935
Fuel Assy. Vol. Fract. (Fuel/Na/Gap/Structure)	0.328/0.419/0.019/0.234
Mixed Oxide Pellet Density (% T.D.)	91.3
Plutonium Wt. Fract., First Cycle : Eq. Cycle (IC/OC)	0.187/0.271 : 0.22/0.32
Isotopic Composition Of Feed Plutonium, 239/240/241/242	0.680/0.194/0.102/0.024
Uranium Isotopic Composition, 235/238 (First Cycle : Eq. Cycle)	0.007/0.993 : 0.002/0.998
Duct And Clad Material	20% CW 316-SS
Peak Fuel Burnup Capability, First Cycle : Eq. Cycle (MWd/T)	30,000 : 150,000
Fissile Plutonium Loading, Start-Of-First-Cycle : Start-Of-Eq.-Cycle, IC/OC (Kg.)	519/630 : 545/668

BLANKET DESCRIPTION:

Axial Blanket Thickness, Upper/Lower (In.)	14/14
No. Of Radial Blanket Assemblies	150
No. Of Radial Blanket Rods Per Assembly	61
Radial Blanket Rod O.D. (In.)	0.520
Radial Blanket Pellet O.D. (In.)	0.485
Radial Blanket Assy. Vol. Fract. (Fuel/Na/Gap/Structure)	0.574/0.256/0.012/0.158
Oxide Pellet Density (% T.D.)	95.6
Uranium Isotopic Composition, 235/238	0.002/0.998

MISCELLANEOUS:

Refueling Interval	Annual
Full Power Capacity Factor, First : Eq. Cycle	0.35 : 0.75
Equilibrium Reload Fraction, Core : Radial Blanket	1/3 : 1/6
Specific Power, First Cycle : Eq. Cycle (MWt/Kg fissile)	0.85 : 0.80
Maximum Linear Power (kW/ft.)	14.5
Equilibrium Assembly Residence Time, Fuel : Radial Blanket (Yrs.)	3 : 6
Blanket Shuffling	IN-OUT

TABLE II

DESIGN MODIFICATIONS TO ENHANCE BREEDING RATIO

<u>DESIGN CHANGE</u>	<u>ESTIMATED INCREASE IN BREEDING RATIO</u>
Additional Row of Radial Blanket Assemblies	0.03
Semi-Annual Refueling	0.02 - 0.03
Reduce Peak Discharge Burnup (150,000 → 80,000 Mwd/T)	0.03 - 0.05
Reduce Radial Blanket Residence Time (6 → 3 years)	0.01
OUT→IN vs. IN→OUT Radial Blanket Shuffling	<0.005
Carbide Radial Blankets	0.03
Increase Upper and Lower Axial Blanket Length (14→18 in.)	0.01
Raise Control Rod Parked Position 5 In. Above Top of Core	0.007
Include Pu ²³⁸ content (1±1%) in Feed Fuel	0.00 - 0.03
Single-Zone-Enrichment Core	0.07
Reduce Clad Thickness (15→10 mils) and Increase Fuel Pellet Diameter (0.1935→0.2035 in.)	0.058
Reduce Pellet/Clad Diametral Gap (6.5→4.5 mils) and Increase Fuel Pellet Diameter (0.1935→0.1955 in.)	0.01
Increase Fuel Pellet Fabrication Density (91.3→95% T.D.)	0.019
Reduce Fuel Rod Pitch-to-Diameter Ratio (1.256→1.20) and Increase Fuel Pellet Diameter (0.1935→0.2035 in.)	0.049
Reduce Fuel Assembly Duct Thickness (120→100 mils)	0.004
Increase Radial Blanket Pellet Diameter (0.485→0.511 in.)	0.02
Increase Axial Blanket Pellet Diameter (0.1935→0.2085 in.)	0.02

TABLE III

COMPARISON OF PROPOSED ADVANCED FUEL AND RADIAL BLANKET ASSEMBLY DESIGNS
WITH FIRST-CORE-DESIGN ASSEMBLIES

	<u>FIRST-CORE DESIGN</u>	<u>INTERIM DESIGN</u>	<u>EQUILIBRIUM DESIGN</u>
<u>FUEL PELLET</u>			
O.D. (Inches)	0.1935	0.2085	0.2085
Density (% of T.D.)	91.3	95	95
Pellet/Clad Diametral Gap (Mils)	6.5	6.5 - 4.5	6.5
<u>FUEL ROD</u>			
Pitch/Diameter Ratio	1.256	1.20	1.1956
Clad O.D. (Inches)	0.230	0.240	0.245
Clad I.D. (Inches)	0.200	0.215 - 0.213	0.215
Clad Thickness (Mils)	15	12.5 - 13.5	15
<u>ASSEMBLY DUCT</u>			
Assembly Pitch (Inches)	4.760	4.760	4.760
Material	20% CW 316-SS	20% CW 316-SS	Low-swelling, High-Strength Steel
O.D., Flat-To-Flat (Inches)	4.575	4.575	4.600
I.D., Flat-To-Flat (Inches)	4.335	4.335	4.400
Wall Thickness (Inches)	0.120	0.120	0.100
Radial Interassembly Gap (Inches)	0.0925	0.0925	0.080
<u>RADIAL BLANKET</u>			
Pellet O.D. (Inches)	0.485	0.485	0.511
Rod O.D. (Inches)	0.520	0.520	0.545
Clad Thickness (Mils)	15	15	15
PEAK BURNUP CAPABILITY MWd/T	80,000	80,000	150,000
EQUILIBRIUM BREEDING RATIO	1.122	1.205	1.224
EQUILIBRIUM FISSILE PLUTONIUM INVENTORY, IC/OC (kg)	545/668	571/682	571/682

FIGURE 1

COMPOUND SYSTEM DOUBLING TIME AS A FUNCTION OF BREEDING RATIO AND LINEAR POWER