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Development of a 150 MWe LMR Conceptual Nuclear Design with Breeding Characteristics

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Abstract

A 150 MWe breeder core planar layout for assuring an economic and safe operation has been developed by equilibrium cycle searches. The fuel cycle analysis was performed in the equilibrium cycle, consisting of external feed fuel with reprocessed typical PWR spent fuel and fissile makeup with recycled Pu. With a few iterations on several candidate core layouts, a reference breeder core of radially heterogeneous configuration has been established. The KALIMER breeder core configuration was developed along with some degrees of optimization subject to the constraint that it approximately fits into the geometric and thermal-hydraulic envelopes similar to the former uranium metallic fueled core. The KALIMER breeder core has an average breeding ratio of 1.18 and maximum discharge burunp of 116.9 MWD/kg. The neutronics performance characteristics obtained from the equilibrium cycle analysis show that the KALIMER breeder core would work safely as well as economically, achieving the design goal of high breeding ratio under the design criteria.

1. Introduction

As a part of the core design development for a prototypical fast reactor, the KALIMER(Korea Advanced Liquid Metal Reactor) core design which uses U-Zr binary fuel not in excess of 20 % enrichment was developed[1], and it underwent optimization processes[2,3]. The uranium metallic fueled core characterized by its negative sodium void reactivity and low power density was proposed to operate with maximizing its core safety characteristics as a first generation LMR(liquid metal reactor). As a next development, it has been recommended that a 150 MWe LMR should be newly designed to enhance the breeding characteristics based on the common perception that the breeding characteristics is one of the main goals for the deployment of fast reactors.

The metallic fueled fast reactor core has a excellent negative reactivity feedback characteristic to enhance inherent safety upon the occurrence of several unprotected transients. In addition, it has a resistance to the nuclear proliferation as well as achieving improved economics with the use of pyroprocessing. Especially the metallic fueled fast reactor offers a number of favorable features regarding management of man-made actinides(transuranics) dominating the long-term radiological toxicity of spent fuel. Nearly all of the transuranic elements are returned to the core in the closed fuel cycle; the waste streams of the metal fuel reprocessing are virtually free of transuranic elements. In addition, because of the particularly hard neutron specturm associated with the metallic fuel, actinides are preferentially fissioned, not converted to still higher actinides. Thus, the available range of breeding characteristics in metallic fueled cores provides for flexibility in transuranic management strategy. Taking advantage of the above, LMR design analyses have focused on the design of cores which are net consumers of transuranics through burning these transuranic isotopes (commonly called 'actinide burner') or which do not require an external source of fissile material in a steady-state metal fuel cycle (called either 'breakeven' or 'high breeding configuration' depending on its breeding gain).

The high breeding core configuration has been developed to achieve the goal of the enhancement of breeding characteristics in the equilibrium cycle. Then the evaluation of the equilibrium cycle has been performed to analyze neutronics performance parameters and some key safety constants of the developed KALIMER breeder core design.

2. Computational Methods and Procedures

The fuel cycle analysis was performed with the nuclear calculation module packages in the K-CORE System[4] which is the standard for the neutronic analysis of fast reactor core in KAERI. Composition-dependent, regionwise 9-group microscopic cross sections were generated from the NJOY-processed 80-group neutron cross section library KAFAX(KAERI FAst XS)/F22[5] by utilizing the effective cross section generation module composing of TRANSX[6] and TWODANT[7] codes.

Fuel cycle calculations were carried out with the neutron flux and burnup calculation module consisting of DIF3D[8] and REBUS-3[9] codes. Flux solution calculations solved the coarse-mesh nodal diffusion theory approach for hexagonal-z reactor representation. For an equilibrium core, the fuel cycle computations for the operating interval under a fixed fuel management scheme were solved; this equilibrium cycle calculation approach approximates reactor characteristics after many cycles of operation subject to a fixed, repetitive fuel management strategy. These calculations were performed with all the control rods withdrawn. In general, the equilibrium cycle analyses provide good estimates of integral parameters, mass flows, and global characteristics of a reactor for an equilibrium state.

Various reactivity feedback effects were calculated utilizing a series of the neutron flux solution calculations for trigonal-z geometry representation and data manipulations with 9-group cross sections. These global reactivity effects are basically determined by the results from direct flux computations for the unperturbed and perturbed systems.

3. Core Configuration Development

The breeder core configuration was developed with the pursuit of maximizing the breeding characteristics, based on the equilibrium cycle calculations. Core configuration for the core design initiation was defined as a heterogeneous core fueled with U-Pu-Zr ternary alloy fuel to enhance the breeding characteristics, taking account of the desired average linear power and maximum power density limit[10]. The starting core layout is D66H90 as shown in Fig.1, where 66 driver fuel assemblies with a fueled region height of 90 cm are loaded in the core. The configuration change in the core planar layout was given only to the active core region from the homogeneous core layout of the KALIMER uranium core. No effort was given to change the arrangement of reflector and its exterior regions, because it would cause many interface problems with the other design groups' activities.

3.1 Nuclear Design Basis and Ground Rules

Core design requirements embracing core design criteria and restraints for metal fuel were made based on the metal fuel database currently available as follows:

- The reactor power shall be 392.0 MWt.
- The capacity factor shall be 85 %.
- The peak linear heat generation heat rate (LHGR) shall be less than 440 W/cm (13.5 kW/ft).
- The local fuel burnup limit shall be 150 MWD/kg.
- The peak fast fluence shall be less than 4.0 x 10^{23} n/cm^2.
- The refueling interval shall be 18 months.
- The fuel form for the core shall be U-Pu-Zr ternary. For the startup core, the fresh fuel is composed of recovered LWR transuranics and depleted uranium. In subsequent cycles, the fissile makeup in the core loading by recycled Pu shall be assumed. In addition, minor actinides shall be assumed to be included with recycled Pu feedstock in the proportions present in the spent fuel.

The present nuclear design was carried out based on the following nuclear design ground rules. These design ground rules identify the important performance parameters in order to assure proper performance and safety of fuel and core;

- The breeding ratio should be over 1.1, without assuming any loss during the reprocessing process.
- Allowable burnup reactivity swing should be around 1000 pcm, and limited to 1500 pcm (~5$) in order to ensure proper reactivity control.
- The average LHGR should be around 7 kW/ft(~230 W/cm). The three-dimensional power peak in the outer core region is desirable, if possible, in order to minimize the sodium voiding potential which might bring about a positive reactivity addition.
- The TRU charge enrichment in the U-Pu-Zr ternary fuel should be less than 30 wt.% to fall within current metallic fuel database[11].

3.2 Phase I Breeder Core Design

Total 16 distinctive core configurations accompanied with the change in the active core height were investigated to identify changes in the nuclear performance parameters. The trial core planar layouts and short summary of equilibrium core nuclear performances are given in Figure 1. From the survey of various core layouts, three candidate core layouts; D42H110, D36H120, and D42H110GEMX were selected for further investigation by the other design areas. The major selection criteria were to pick up configurations of which driver average LHGR is around 7 kw/ft and its breeding ratio is well over 1.1. According to the extensive review, the D42H110 configuration proved to be the favorite; the D36H120 configuration was pointed out as having too high an average LHGR and too lengthy a fission gas plenum. The D42H110GEMX configuration was recommended to be thrown away for the consideration due to the absence of GEM. As a result, the D42H110 configuration was selected as the design for further analysis.

3.3 Phase II Breeder Core design

For the D42H110 core layout, the thermal-hydraulic(T/H) performance analysis showed that it failed to satisfy the newly set design limit for peak clad midwall of 630 °C. The increase in the number of fuel rods within an assembly or the reduction of nominal core outlet temperature were proposed as possible options to overcome this problem. Since the increase in the number of fuel rods would necessitate assembly restructuring and eventually imposes a significant increase in the fuel rod manufacturing requirements, a nominal core outlet temperature was determined to be reduced to 500 °C from the previous 530 °C, which will degrade the plant thermal efficiency by about 2 %.

The REBUS equilibrium cycle analysis does not account for the cyclic peak power density change which will show up in the explicit non-equilibrium cycle analysis. Namely, the equilibrium cycle model underestimates the maximum power density by mixing up number densities in a few stages. To account for the maximum power density and linear power given in the explicit non-equilibrium cycle, the ratio of the maximum power density for the explicit non-equilibrium cycle model to that for the equilibrium cycle calculation, is defined as a batch factor. Among several non-equilibrium cycle models differing in the reloading schemes, a reloading scheme having the minimum batch factor was identified from the cycle-by-cycle peak power density evolutions. As was expected, the introduction of batch factor to the previous D42H110 core design analysis, resulted in too high a pressure loss in the active core to keep the 2σ clad midwall temperature below 630°C[12].

With the reduction of core average LHGR adopted, alternative core design search became diverse in order to find the core design which satisfies both the maximum allowed clad midwall temperature limit of 630 °C and maximum allowed core pressure loss of 0.63 MPa. The design alternatives with the core layouts; D36H140, D42H120, D48H110 and D48H120 were selected. For the D36H140 design which is excellent in breeding characteristics and fuel cycle economics, there appeared concerns for violating design criteria upon their application in a conservative manner and the fuel handling machine accommodation capability. The D42H120 design showed that the maximum pressure loss across the core reaches 0.75 MPa. While there are some possibilities that the D48H110 design can suffice the very restrictive design criteria with nominal outlet temperature of 500°C, the D48H120 design proved to open the potential for satisfying the design criteria even at the elevated nominal outlet temperature of 530°C. Therefore, the D48H120 core design was determined to be the reference breeder core design for the further analysis with the elevated nominal core outlet temperature of 530°C. This strategy keeps the high plant overall thermal efficiency, and thus does not sacrifice the plant electricity output of 150 MWe.

4. Reference Breeder Reactor Analysis

4.1 Description of Reference Core Design

The reference core(D48H120) planar layout is shown in Figure 1. The core configuration was developed to enhance the breeding characteristics, and thus utilizes a radially heterogeneous core configuration. There are no axial blankets surrounding the core, due to a good breeding capacity characteristic of a metal fuel. The arrangements beyond the reflector are the same as those for the former uranium metallic fueled core[1]. As described in Section 3, the core configuration was developed to some degrees of optimization subject to the constraint that it approximately fits into the geometric and thermal-hydraulic envelopes similar to the former uranium metallic fueled core.

General reactor specifications such as operating conditions and design parameters for core and assemblies are given in Table 1. The design geometry parameters adopt the new specification for gas plenum. The driver fuel assembly uses a single enrichment and its fuel form is U-Pu-10%Zr ternary alloy. The driver fuel and blanket have smeared densities of 75 % and 85 %, respectively. One-third of the driver fuel and the internal blanket assemblies, and one-sixth of blanket assemblies are refueled during each outage. Only a scatter loading was assumed and, therefore the fuel and blanket assemblies are not shuffled, but remain in position for the entire cycles. Shuffling can be performed to reduce cyclic peaking behaviors in the equilibrium cycle. Following removal from the core, they decay for one operating cycle in the IVS positions.

4.2 Reference Equilibrium Cycle Analysis

4.2.1 Nuclear Performance

Neutronic core performance parameters were obtained from the REBUS-3 equilibrium cycle calculations. In order to facilitate hexagonal-z and trigonal-z calculations with the same model, the modeling was set up for the trigonal-z model in 60 degree sector of the core. The BOEC to EOEC depletions modeled five distinctive time nodes, with the prestored burnup chain model having descriptions for all the U-Pu-MA isotopes. The fuel cycle analysis was given for the equilibrium fuel cycle consisting of startup fuels with typical PWR spent fuel [13] and fissile makeup with recycled Pu. The IVSs were loaded with the spent fuels discharged from driver fuel, inner and radial blankets for one cycle cooling according to the fuel management scheme before eventual removal from the reactor. Fuel feed enrichment requirements were determined from the flux and burnup calculations to achieve k_{eff} = 1.002 at the end of the equilibrium cycle(EOEC).

The neutronic core performance parameters for an equilibrium cycle are summarized in Table 2. The Pu fissile fraction requirement for fuel feed is 20.49 %, corresponding to total Pu fraction of 25.84 % of the fuel alloy. The burnup reactivity swing is 632 pcm. This low burnup reactivity loss leads to reduced control system manipulations as well as to a decrease in the reactivity available to a potential control rod-ejection accident. The average breeding ratio is 1.182 and the fissile Pu gain per cycle is obtained to be 37.3 kg, which satisfies the design goal of high breeding ratio associated with positive system fissile gain. The peak fuel discharge burnup of 116.9 MWD/kg and peak fast fluence of 2.43×10^{23} n/cm^2 manifests that there are some optimization potentials to lengthen the cycle length or increase batch number of driver assemblies. The peak linear power of 286.5 W/cm lies within the design criteria limit of 400 W/cm. Since radial blankets are operated in six batches, the fast fluence (3.51×10^{23} n/cm^2) approaches its design limit of 4.0×10^{23} n/cm^2.

4.2.2 Reactivity Feedbacks and Control System Worths

Global reactivity feedbacks resulting from the Doppler effect, uniform radial expansion, and various sodium voidings in the equilibrium core are given in Table 3, including the reactivity worths of the control rod system, GEM(gas expansion module), and USS(ultimate shutdown system).

From the regression analysis, the fuel temperature (Doppler) coefficients due to the Doppler effect were estimated on the basis of $1/T^{1.43}$ variation, which shows that the present plutonium core has a hard neutron spectrum for a small, metallic fueled fast reactor. The fuel temperature coefficients do not show any substantial change with burnup. In the sodium-voided case, the fuel temperature coefficient becomes less negative, compared with the flooded case. They were evaluated to vary as $1/T^{1.49}$, manifesting the spectrum hardening due to sodium voiding.

The sodium void worths for the total voiding in the active core were evaluated to be 1773 pcm at BOEC and 1948 pcm at EOEC, respectively. For the partial voiding, all the regions have a positive sodium void worth. These high positive void worths result from the high core height of 120 cm and the large effective core consisting of 48 driver fuel assemblies. It was estimated that even the activation of GEM is not sufficient to bring the core subcritical. The sodium void worths increase in their magnitude with burunup, which is due to the inward shift of the radial power peaking location.

The uniform core radial expansion due to the coolant temperature rise is one of major negative reactivity insertion mechanisms in metallic fueled reactor. The regression analysis produced the radial expansion coefficients of –252 pcm/% radial volume and –126 pcm/% radial expansion, respectively. When coupled with the linear thermal expansion for the core structure, the radial expansion coefficient is given by -7.40×10^{-4} K^{-1}. The radial expansion coefficients are insensitive to the burnup and degree of radial expansion.

The total control rod worths were estimated to be invariantly about 10,400 pcm during an operation cycle and have a weak dependence on fuel enrichment variation and spectrum change with burnup. The estimated total control rod worth implies a sufficient shutdown potential to bring the core subcritical even in the sodium voided cases. The induced negative reactivity from GEM activation only is not enough to bring the core subcritical in any sodium voided conditions. It is remarkable, however, that even the maximum positive sodium void worth induced from the sodium voiding can be overcome with the introduction of a passive shutdown system, USS.

5. Summary and Conclusion

The KALIMER breeder core planar layout for an economic and safe configuration was explored by varying the core planar layout associated with the volume ratio of driver fuel to blanket, and core height, in the equilibrium cycle. With a few iterations on several candidate core layouts, a reference core of radially heterogeneous configuration has been established. The KALIMER breeder core configuration was developed to some degrees of optimization subject to the constraint that it approximately fits into the geometric and thermal-hydraulic envelopes similar to the former uranium metallic fueled core. Therefore, the reference core configuration has potential for improvements in the viewpoint of the core compactness, economy and safety, compared with other elaborate core designs. Since the current design is marginal to meeting the design criteria for the clad midwall temperature and the core pressure drop, the relaxation of the design criteria would allow a further optimization of the KALIMER breeder reference design to happen.

The KALIMER breeder core has an average breeding ratio of 1.18 and maximum discharge burunp of 116.9 MWD/kg. The neutronic performance analysis based on the equilibrium cycle calculations shows that the KALIMER breeder core is satisfactorily designed to achieve the design goal of high breeding ratio under the design criteria. No effort was given to optimize the fuel loading pattern in the present reference breeder core design. In addition, there was no attempt to change the arrangements beyond the reflector. Further optimizations of core layout and fuel management strategy for improved fuel cycle economics shall be needed as future works.

Acknowledgement

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Table 1. KALIMER Breeder Core Design Specification

Operating Conditions	
Core Thermal Power (MWt)	392.2
Core Electric Power (MWe)	150.0
Core Mixed Mean Inlet/Outlet Temp.(°C)	386.2/ 530.0
Plant Capacity Factor (%)	85.0
Core Configuration	Heterogeneous
Number of Core Enrichment Zones	1
Feed Fuel Composition	LMR Recycled
Refueling Interval (months)	18
Effective Full Power Day (EFPD)	465
Number of Batches	
Driver Fuel	3
Inner Blanket	3
Radial Blanket	6
Core and Assembly Design Parameters	
Core	
Active Core Height (cm)	120.0
Core Diameter (cm)	344.3
Core Structural Material	HT9
Assembly	
Fuel Material (Driver Fuel/Blanket)	U-Pu-10Zr/U-10Zr
Smeared Density (%)	75/85
Active Fuel Length (cm)	120.0
Fuel Element Length (cm)	389.3
Overall Assembly Length (cm)	484.7
Duct Pitch (mm)	161.0
Duct Gap (mm)	4.0
Duct Wall Thickness (mm)	4.0
Pins per Fuel Assembly (Driver/Blanket)	271/ 127
Pin Outer Diameter(Driver/Blanket) (mm)	7.40/ 12.00
Pin P/D Ratio (Driver/Blanket)	1.203/1.083
Upper Fission Gas Plenum Length(/Na Filled) (cm)	155.0/ 20.0

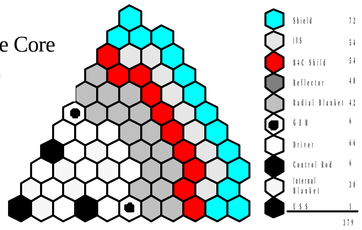
Table 2. Summary of Nuclear Performance

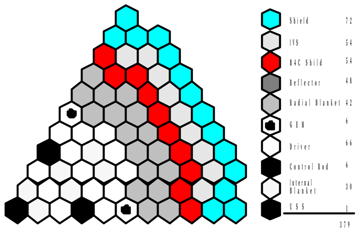
Average Breeding Ratio	1.182
Refueling Interval (months)	18
Burnup Reactivity Swing (pcm)	632.2
Average Fuel Burnup (MWD/kg.cycle)	
Driver Fuel	25.9
Inner Blanket	6.2
Radial Blanket	2.8
Average Driver Fuel Assembly Discharge Burnup (MWD/kg)	79.8
Peak Fuel Discharge Burnup(MWD/kg)	116.9
Feed Driver Fuel TRU Enrichment (%)	26.30
Fissile Inventory at BOEC/EOEC (kg)	1253.3/1288.3
Supplied Fissile Pu (kg/cycle)	354.3
Total Fissile Gain (kg/cycle)	34.4
Average Linear Power at BOEC/EOEC (W/cm)	
Driver Fuel	184.8/170.3
Inner Blanket	126.2/176.5
Radial Blanket	41.1 / 49.0
Peak Linear Power at BOEC/EOEC (W/cm)	
Driver Fuel	278.3/255.2
Inner Blanket	209.2/286.5
Radial Blanket	182.1/203.2
Power Peaking Factor for Driver Fuel	
BOEC/ EOEC	1.51/1.50
Peak Neutron Flux (x 10^{15} cm^2/sec)	
Driver Fuel (BOEC/ EOEC)	2.96/3.00
Peak Fast Fluence (x 10^{23} n/cm^2)	
Driver Fuel	2.43
Inner Blanket	2.39
Radial Blanket	3.51

Table 3 Summary of Reactivity Worths

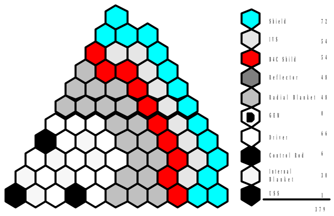
	BOEC	EOEC
Fuel Temperature (Doppler) Coefficient (Δk/k/K)		
Flooded	-0.1031 $T^{-1.43}$	-0.1042 $T^{-1.43}$
Voided	-0.1169 $T^{-1.49}$	-0.1098 $T^{-1.48}$
Uniform Radial Expansion Coefficient		
(dk/k)/ (dR/R) (pcm/%)	-126	-126
dk/dT (x 10^{-4})(K^{-1})	-7.4755	-7.3811
Sodium Void Effect(pcm)		
Driver Fuel (DF)	1,002	1,116
Inner Blanket (IB)	793	821
DF + IB	1,839	1,977
Total (DF + IB + RB)	1,773	1,948
DF + IB + GEM	847	1,062
DF + IB + RB + GEM	791	1,043
Control Rods (pcm)	10,422	10,408
GEM(pcm)	-887	-810
USS(pcm)	2,351	2,791

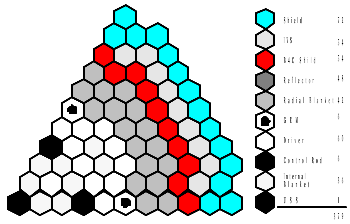
Phase I Reference Core
(D66H90)



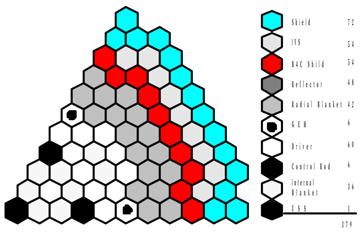


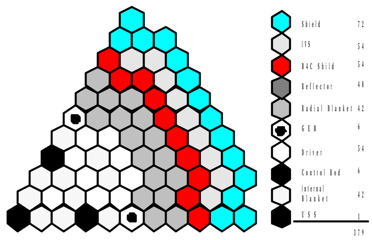
Design Parameter	D66 Height (cm)				D66 % Power			
	90	100	110	120	90	100	110	120
Breeding Ratio	1.01205	1.05066	1.08600	1.11483	1.01708	1.01205	1.00683	1.00174
Reactivity Swing(pcm)	1227	790	445	173	1095	1227	1366	1508
3-D Peak Power Density(w/cc)	347	319	296	276	316	347	378	408
Peak Location(r,s)	3,2	3,2	3,2	3,2	3,2	3,2	3,2	3,2
Driver Avg. Disch. Burnup(a/o)	8.68	7.85	7.16	6.6	9.74	8.68	9.45	12.57
Driver Avg. LHGR(kW/ft)	5.88	5.31	4.84	4.46	5.33	5.88	6.42	6.95
Feed Enrichment(Pu v/o)	30.00	27.92	26.40	25.24	29.77	30.00	30.27	30.54





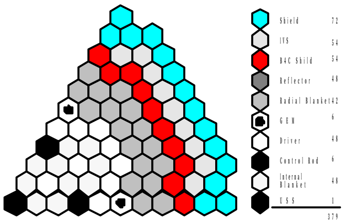
Design Parameter	D66GEMX Height (cm)				D66FAT Height (cm)			
	90	100	110	120	90	100	110	120
Breeding Ratio	1.04178	1.08198	1.11720	1.14784	1.03849	1.07856	1.11343	1.14404
Reactivity Swing(pcm)	1093	658	316	50	916	491	161	-98
3-D Peak Power Density(w/cc)	341	315	292	273	352	323	300	280
Peak Location(r,s)	3,2	3,2	3,2	3,2	3,2	3,2	3,2	3,2
Driver Avg. Disch. Burnup(a/o)	8.56	7.74	7.07	6.51	7.96	7.19	6.57	6.05
Driver Avg. LHGR(kW/ft)	5.81	5.24	4.79	4.40	5.91	5.34	4.87	4.48
Feed Enrichment(Pu v/o)	28.96	27.04	25.63	24.57	26.80	25.04	23.76	22.77

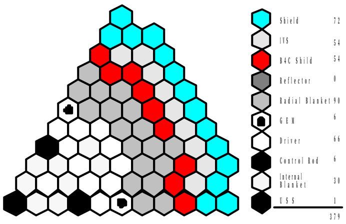




Design Parameter	D60 Height (cm)				D54 Height (cm)			
	90	100	110	120	90	100	110	120
Breeding Ratio	0.99457	1.03314	1.06644	1.09579	1.00760	1.04664	1.08088	1.11087
Reactivity Swing(pcm)	1787	1352	1013	744	1401	978	648	388
3-D Peak Power Density(w/cc)	366	335	310	289	398	364	337	313
Peak Location(r,s)	5,1	5,1	5,1	5,1	5,2	5,2	5,2	5,2
Driver Avg. Disch. Burnup(a/o)	8.70	8.53	7.79	7.17	10.17	9.19	8.39	7.72
Driver Avg. LHGR(kW/ft)	6.41	5.78	5.28	4.85	6.92	6.25	5.70	5.24
Feed Enrichment(Pu v/o)	34.47	32.09	30.35	29.03	38.37	35.75	33.86	32.43

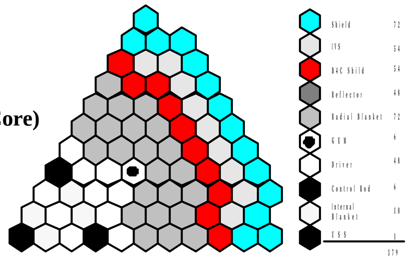
Figure 1. Trial Core Planar Layouts and Their Performance Parameters for KALIMER Phase I Breeder Design



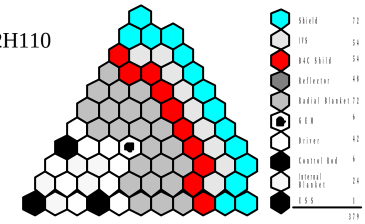


Design Parameter	D48				D66			
	Height (cm)				Height (cm)			
	90	100	110	120	90	100	110	120
Breeding Ratio	0.99472	1.03331	1.06696	1.09612	1.05778	1.10003	1.13661	1.16871
Reactivity Swing(pcm)	1546	1131	807	555	1924	1484	1138	862
3-D Peak Power Density(w/cc)	415	380	351	327	365	335	310	288
Peak Location(r,s)	6,2	6,2	6,2	6,2	5,1	5,1	5,1	5,1
Driver Avg. Disch. Burnup(a/o)	11.27	10.17	7.81	8.55	8.62	7.92	7.33	6.82
Driver Avg. LHGR(kW/ft)	7.68	6.93	6.32	5.81	6.38	5.76	5.26	4.84
Feed Enrichment(Pu v/o)	45.01	42.00	39.79	38.14	33.02	30.91	29.37	28.18

D48H120 (Breeder Reference Core)

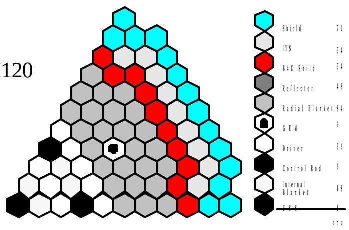


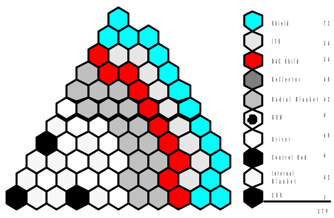
D42H110



Design Parameter	D48				D42			
	Height (cm)				Height (cm)			
	90	100	110	120	90	100	110	120
Breeding Ratio	1.04197	1.08695	1.12673	1.16144	1.05214	1.09881	1.13961	1.17543
Reactivity Swing(pcm)	2320	1731	1260	888	2205	1595	1113	731
3-D Peak Power Density(w/cc)	441	407	377	351	538	492	455	423
Peak Location(r,s)	3,1	3,1	3,1	3,1	3,1	3,1	3,1	3,1
Driver Avg. Disch. Burnup(a/o)	11.39	10.27	9.37	8.63	12.55	11.32	10.32	9.50
Driver Avg. LHGR(kW/ft)	7.78	7.02	6.40	5.88	8.64	7.79	7.10	6.52
Feed Enrichment(Pu v/o)	31.90	29.54	27.81	26.53	36.48	33.75	31.78	30.30

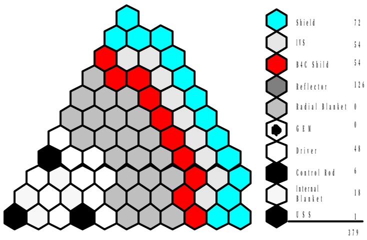
D36H120



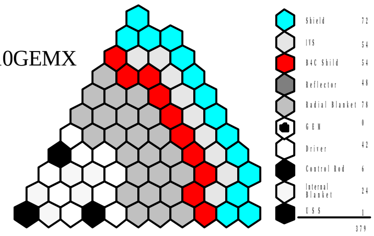


Design Parameter	D36				D60GEMX			
	Height (cm)				Height (cm)			
	90	100	110	120	90	100	110	120
Breeding Ratio	1.06609	1.11409	1.15653	1.19384	1.03694	1.07758	1.11312	1.14368
Reactivity Swing(pcm)	3043	2343	1782	1333	1220	802	476	225
3-D Peak Power Density(w/cc)	588	538	497	463	395	362	335	312
Peak Location(r,s)	3,1	3,1	3,1	3,1	5,2	5,2	5,2	5,2
Driver Avg. Disch. Burnup(a/o)	14.34	12.93	11.79	10.85	10.02	9.05	8.27	7.62
Driver Avg. LHGR(kW/ft)	9.93	8.94	8.14	7.49	6.83	6.17	5.63	5.18
Feed Enrichment(Pu v/o)	36.33	33.56	31.54	30.03	37.18	34.78	33.02	31.71

Figure 1. continued



D42H110GEMX



Design Parameter	D48GEMX Height (cm)				D42GEMX Height (cm)			
	90	100	110	120	90	100	110	120
Breeding Ratio	0.71302	0.74987	0.78074	0.80672	1.07678	1.12445	1.16609	1.20239
Reactivity Swing(pcm)	3864	3105	2501	2018	2082	1479	1003	628
3-D Peak Power Density(w/cc)	479	439	406	378	526	481	445	415
Peak Location(r,s)	3,1	3,1	3,1	3,1	3,1	3,1	3,1	3,1
Driver Avg. Disch. Burnup(a/o)	13.02	11.76	10.72	9.87	12.43	11.21	10.23	9.42
Driver Avg. LHGR(kW/ft)	8.76	7.91	7.22	6.64	8.57	7.72	7.04	6.47
Feed Enrichment(Pu v/o)	38.62	36.13	34.20	32.67	35.43	32.87	31.01	29.61

Figure 1. continued