ABB TURBO™ ADVANCED FUEL FOR APPLICATION IN SYSTEM 80® FAMILY OF PLANTS

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ABSTRACT

ABB Combustion Engineering Nuclear Operations (ABB CE) has developed an Advanced Fuel Design, tailored to the Combustion Engineering, Inc. (CE) Nuclear Steam Supply System (NSSS) environment. This Advanced Fuel Design called Turbo™ features a full complement of innovative components, including GUARDIAN™ debris-resistant spacer grids, Turbo™ Zircaloy mixing grids to increase thermal margin and grid-to-rod fretting resistance, value-added fuel pellets to increase fuel loading, advanced cladding to increase achievable burnup, and axial blankets and Erbium integral burnable absorbers for improving fuel cycle economics.

This paper summarizes the Turbo™ Fuel Design and its application to a System 80® family type plant. Benefits in fuel reliability, thermal margin, improved fuel cycle economics and burnup capability are compared relative to the current ABB CE standard fuel design. The fuel management design and the associated thermal margin are also evaluated.

1. INTRODUCTION

This paper presents information for the Turbo™ fuel design, fuel management and the associated thermal margin for a 1100 MWe System 80® nuclear power plant for Asia. The fuel cycle design for the plant is based upon 30 years of ABB CE's experience in the design, construction, and operation of modern pressurized water reactors (PWRs). The core and fuel design features included in this plant are well-proven in operating reactors, and reflect the ABB CE nuclear design philosophy used in the evolution of the System 80® power plant design. As a result, the System 80® plant includes benefits of a fuel management and fuel design that combines low cost, high thermal margin and excellent operating flexibility, together with features that are proven in operating plants in the United States, South Korea and Europe.

The System 80® fuel design and fuel management incorporate a variety of proven design features that reduce costs, improve availability, and increase thermal margin. In addition, the plant design and analysis methodology include other features to enhance economical operation. These features are described in the following sections.

2. SYSTEM 80® FUEL DESIGN FEATURES

The current ABB CE's standard fuel design has been proven to be a rugged, reliable design that has led the industry in meeting the Institute of Nuclear Power Operations (INPO) Fuel Reliability Indicator for 23 out of the past 24 months. One of the main reasons for this success is the use of a robust all Zircaloy fuel assembly design with 5 large guide tubes and the application of an extensive development and qualification process to implement the fuel design in-reactor. ABB CE has always used a cautious systematic process when introducing new features into our plants. This process includes a full set of qualification tests performed at reactor operating conditions and extensive Lead Fuel Assembly (LFA) programs for in-reactor demonstration. As a result of this process no fuel failure has ever been attributed to the introduction of a new fuel design feature by ABB CE.

ABB CE has now developed the Turbo™ Fuel Design to meet the future needs of our customers. These needs include improved fuel reliability, improved fuel cycle economics, higher burnup capability and improved performance. The Turbo™ fuel design features are shown in Figure 1 and the benefits are summarized below. Further detail on Turbo™ fuel can also be obtained from Reference 4.

Fuel Assembly Description

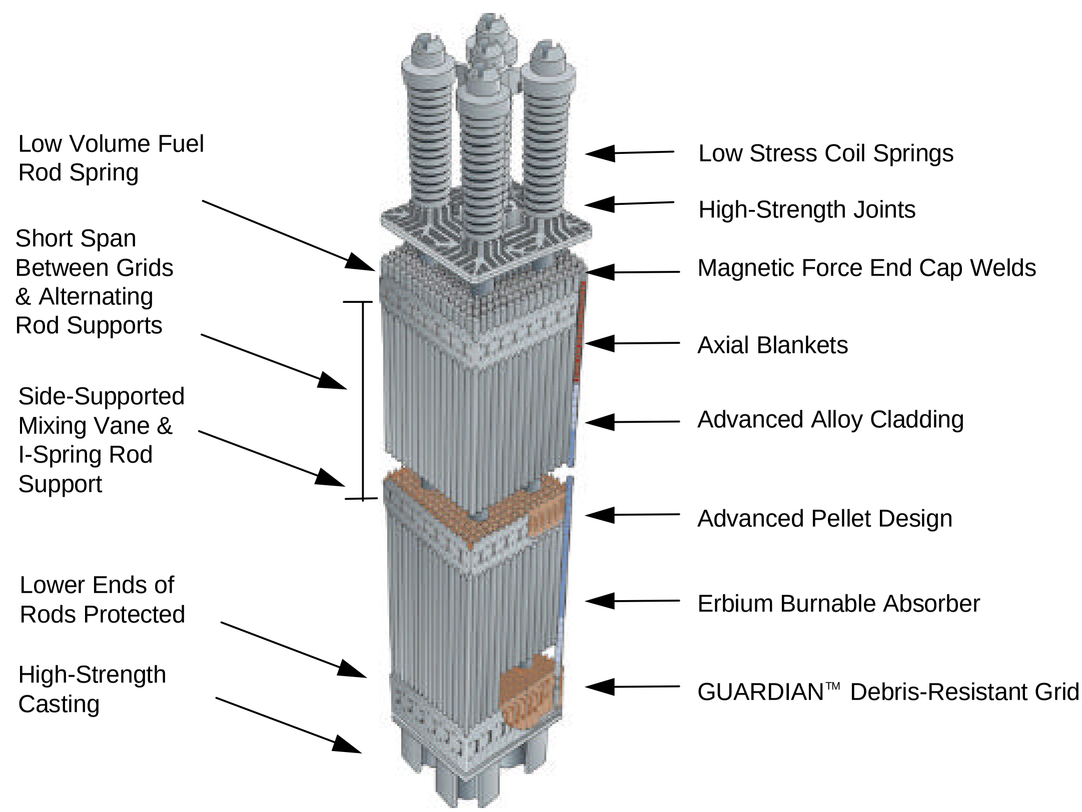

Figure 1 Fuel Assembly Description

2.1 Erbium Integral Burnable Absorbers

The erbium integral burnable absorber was developed by ABB CE specifically for application in long (18 to 24 month) fuel cycles. The use of erbium as a burnable absorber results in a substantial gain in power operating margin over that available with the use of other burnable absorbers for the long fuel cycles typical of those proposed for Asia (See Reference 1). With proper design, erbium fuel managements have both lowest cost and thermal margin benefits.

The typical fuel assembly configuration using erbium integral burnable absorber rods contains a moderate number (24-68) of erbium-bearing fuel rods per assembly. The erbium burnable absorber rod consists of a normal, UO_2 fuel pellet with a low (2.1 wt% or less), uniform concentration of erbium in solid solution. Erbium is a rare earth element similar in physical, chemical and mechanical properties to gadolinium. Neutronically, the cross section of erbium in the thermal energy region is similar to that of boron. However, unlike other burnable absorbers, erbium exhibits a neutron absorption cross section that increases in the epithermal energy region. As a result, the neutron flux shift accompanying a rise in moderator temperature results in a more negative moderator temperature coefficient (MTC) for erbium, thus reducing the amount of erbium required to achieve an acceptable MTC. In addition since erbium is a dilute burnable absorber, local power peaking is low. The reduced power peaking significantly improves thermal margin, making more advanced and more economical fuel managements possible (Reference 1).

The benefits of erbium compared to other burnable absorbers (B_4C, gadolinium and boron coated pellets) are summarized below.

- Erbium is a dilute absorber, unlike gadolinium or boron carbide (B_4C), and thus does not adversely effect local power peaking. This is a substantial benefit, resulting in increased thermal margin.
- At concentrations of 2.1 wt% or less, erbium has no significant effects on the material properties of UO_2. Consequently there is no need to reduce the uranium 235 (U-235) carrier enrichment, thus providing improved thermal margin and reduced fuel cycle costs.
- The depletion of erbium is slower than that of other burnable absorbers, and closely matches the depletion of the fuel. As a result, peaking is well-controlled throughout the fuel cycle. By contrast, peaking in a core using boron-coated fuel pellets typically increases for approximately the first 6000 MWD/MTU of the fuel cycle.
- No helium is generated in erbium burnable absorber rods, so the accommodation of fission gas release at high burnup is simplified relative to a core containing boron-coated fuel pellets.
- The addition of erbium does not increase the tendency of the fuel pellets to pick up moisture, as is the case with boron-coated fuel pellets. Therefore special fabrication techniques are not needed, thereby reducing fuel manufacturing costs and decreasing the potential for hydride failures due to errors in fuel fabrication.
- The increased cross section of erbium in the epithermal energy region provides a negative component to the moderator temperature coefficient (MTC). Therefore, fewer erbium rods are needed to maintain a negative MTC early in the fuel cycle, which is one of the primary functions of the burnable absorber in long fuel cycles.
- Lower initial concentrations of erbium help reduce the end of cycle residual reactivity worth, thereby improving fuel utilization and reducing fuel cycle costs.
- A fuel cycle cost savings of 1 to 3% was estimated relative to other burnable absorbers (gadolinia and ZrB_2) for the proposed 18 month cycle of the System 80® plant and an 8% improvement in thermal margin was estimated compared to using gadolinia.

2.2 Value-Added Fuel Pellets

Over the years, ABB CE has performed a variety of evaluations of the most appropriate fuel lattice parameters, frequently characterized by the water-to-fuel ratio (References 2 and 3). The choice of fuel rod diameter impacts several performance aspects of the fuel, including heat transfer surface area, coolant flow characteristics, mechanical design and fuel reliability. These aspects are basic to the development of the fuel lattice design, in addition to the neutronic and economic evaluations. ABB-CE has consistently concluded that a reduction in the diameter of the fuel pellet, resulting in an increase in the lattice hydrogen-to-uranium (H/U) ratio, would not result in an economic benefit. Further, use of thinner fuel rods to increase the H/U ratio would in general be detrimental to thermal margin and fuel reliability.

However, increasing the amount of uranium in the fuel rod has an economical benefit, with no negative impact on thermal margin. Therefore, in 1992, ABB-CE introduced the value-added fuel pellet design. This change increased the density and the diameter of the pellet and reduced the dish and chamfer volume relative to previous pellet designs. These changes resulted in an increased fuel loading of 2 to 3%. The value-added fuel pellet design allows ABB-CE to either design longer cycles with the same number of fresh fuel assemblies, or reduce the number of fresh fuel assemblies required in each fuel cycle. In each case, a decrease in fuel cycle costs of ~1% is derived. The value-added fuel pellet is now a standard part of the System 80® fuel design.

2.3 Advanced Cladding

The Turbo™ fuel design features advanced alloy cladding to achieve higher burnup. ABB-CE's current optimized, low-tin, OPTIN™ Zircaloy-4 cladding has performed well to burnups of at least 60 GWD/MTU. Measurements have demonstrated that OPTIN™ cladding provides a significant improvement in corrosion resistance (40 to 50%) compared to normal-tin Zircaloy-4 cladding and the measured oxide thickness for OPTIN™ at 66 GWD/MTU was less than 100 microns with no spalling. Programs are ongoing to extend the burnup limit of the current OPTIN™ cladding to 65 GWD/MTU.

ABB CE is also developing advanced alloys capable of achieving even higher burnups. Post-irradiation examinations of these advanced alloys has shown significant improvement in corrosion resistance compared to the current OPTIN™ cladding. Advanced cladding materials have been developed to achieve peak rod burnups above 70 GWD/MTU. These cladding materials show at least 45% improvement in corrosion resistance relative to ABB CE's present OPTIN™ cladding material. The advanced cladding materials also show 30 to 40% lower axial growth compared to the current cladding. The lower axial growth in the cladding increases the available gap between the rod and nozzles. Lead test rods of the advanced cladding materials are being irradiated in ABB CE 14x14 and 16x16 plants and full assembly quantities began irradiation in early 1997.

2.4 Axial Blankets

Axial blankets provide improved fuel cycle economics through reduction in the neutron leakage from the top and bottom of the core. Axial blankets are implemented by reduced U-235 enrichment at the ends of all fuel rods. In general, axial blankets increase the axial power peaking, although the effect is significantly reduced by use of additional axial cutbacks at the top and bottom of the burnable absorber rods. This cutback flattens the axial power distribution during the initial part of the operating cycle, thus mitigating the thermal margin impact of the axial blankets. Also, ABB CE does not need annular pellets in the blanket region due to large fission gas plenum in the fuel rod.

ABB-CE has performed numerous evaluations of PWR axial blanket designs for various fuel managements in order to optimize the economic benefit and the impact on thermal margin. In general, the use of seven

(7) inch axial blankets at the top and bottom of the reactor core provides the highest achievable uranium resource benefit with acceptable thermal margin impact. The use of low, 2.5 wt.% U-235 in the axial blankets in combination with erbium burnable absorber rod cutbacks of approximately fourteen (14) inches is a standard feature of the System 80® fuel design for Asia. The resultant fuel cost savings is 2 to 3% for the System 80® design.

2.5 Zircaloy Mixing Grids

The Zircaloy mixing grids contained in the Turbo™ fuel design provide further reduction in the potential for fuel rod fretting relative to the current grid design, support longer fuel cycles, and significantly increases core thermal margin. The Zircaloy mixing grids feature straight Zircaloy strips, an improved rod support system with a patented axial “I-spring”, and side-supported mixing vanes. The straight strip configuration results in a grid that is both stronger and stiffer than the current grid. The “I-Spring” rod support system significantly reduces rod fretting wear by increasing contact area and maintaining contact with the fuel rod through out life in-reactor. Also backup arches are located at the ends of the “I” spring in all grid cells to prevent damage of spring due to fuel handling. Out-of-pile endurance tests for the “I” spring indicate a factor of 4 improvement in rod wear compare to the current standard ABB CE grid design. Qualification testing of the Turbo™ 14x14 grid is completed and LFAs are under irradiation. A 16x16 Turbo™ grid is now in development. The side-supported mixing vanes are also designed to allow fuel reconstitution from the top of the assembly, and provide significant benefits with respect to thermal margin, as described below.

The patented side-supported mixing vanes have been proven to be very effective in generating a strong swirl in the subchannel that persists the entire grid span. This swirl enhances heat transfer from the surface of the fuel rod, thus increasing the critical heat flux required to cause DNB. The difference in critical heat flux of the advanced Zircaloy grid design compared to a grid with no mixing vanes has been demonstrated from critical heat flux testing to provide an average improvement of 44% in DNBR performance. This large improvement in DNBR performance easily supports a 10 to 15% increase in overpower margin for the System 80® plant.

The side-supported mixing vanes also have the added benefit of reducing waterside corrosion due to improved heat transfer. 3-D computational fluid dynamic calculations of a subchannel downstream of the side-supported mixing vane indicate an average 30% improvement in heat transfer. This large improvement in heat transfer is expected to reduce corrosion and subcooled boiling duty on the surface of the rod. The reduction in subcooled boiling also mitigates the formation of crud and Axial Offset Anomalies. The side-supported mixing vane puts more emphasis on swirling flow in the subchannel as opposed to mixing flow between channels. As a result the large improvement in DNB performance for the side-supported mixing vanes will not be diminished due to flatter power distributions that characterize fuel management designs using erbia integral burnable absorbers.

2.6 GUARDIAN™ Debris-Resistant Grids

The patented GUARDIAN™ debris-resistant grid which is located just above the inlet flow nozzle increases the reliability of ABB CE’s proven rugged fuel design. Presently, 23 batches of GUARDIAN™ fuel have been operating in ABB CE plants with no debris-related fuel failures. Implementation of the GUARDIAN™ grid has been a key contributor to ABB CE’s industry leading performance of meeting the INPO Fuel Reliability Indicator 23 out of the past 24 months.

3. SYSTEM 80® FUEL MANAGEMENT DESIGN FEATURES

3.1 18-Month Fuel Cycle

ABB CE recommends fuel cycle lengths of at least eighteen months in order to improve plant availability. ABB CE has lead the U.S. nuclear industry in the implementation of long fuel cycles. All PWRs supported by ABB CE operate on fuel cycles of at least eighteen months. Further, there are currently four (4) ABB CE fueled PWRs operating on 24 month cycles; the first such "extra" long cycle was started in 1988.

3.2 Dual Reload Batches and Enrichment Zoning

Another design feature used extensively by ABB CE is dual reload batches, whereby fuel rods of two different uranium enrichments are used in a single reload batch. Further, the ABB-CE fuel design allows for enrichment zoning, in which differently enriched rods are selectively mixed in different regions of the fuel assemblies. Enrichment zoning can be used to reduce power peaking both within a fuel assembly and in the core, and thus provide an increase in core thermal margin. Enrichment zoning can also improve fuel utilization and permit more flexible fuel management schemes.

The dual reload batch and enrichment zoning features are demonstrated in the fuel management information presented for the 1100 MWe System 80® plant design for Asia. As shown in Table 3, the equilibrium reload batch of 60 fuel assemblies contains fuel assemblies of two different U-235 enrichments (low and high) and has six (6) sub-batches. The sub-batches vary by the number of each of the three different types of fuel rods; lower-enrichment U-235 rods, higher-enrichment U-235 rods, and erbium burnable absorber rods in the assemblies that make up each sub-batch. The design flexibility of these six sub-batches enables a reduction in core peaking and provides an increase in thermal margin that can be used to achieve advanced, low-cost core configurations.

3.3 Low Leakage Loading Pattern

ABB CE uses low leakage (IN-IN-OUT) fuel management schemes in all of its core designs. The principal benefit of low leakage fuel management schemes is a reduction in fuel cycle costs resulting from improved uranium and enrichment utilization. Low leakage fuel management also provides a means of achieving higher average fuel discharge burnups, which provides further reduction in fuel cycle costs. ABB CE's experience has shown typical savings of 5-10% in fuel cycle costs using low leakage extended burnup fuel managements, relative to conventional OUT-IN-IN fuel managements. Another benefit of low leakage fuel management is a reduction in the neutron fluence to the reactor pressure vessel.

3.4 High Fuel Discharge Burnup

ABB CE has always been an industry leader in licensing and implementing high discharge burnup fuel managements. ABB CE was the first fuel vendor in the U.S. to receive NRC approval for the 52 GWD/MTU burnup limit, and subsequently first to receive approval for the 60 GWD/MTU burnup limits. ABB CE is currently proceeding with work that is expected to result in an NRC license in 1999 for 65 GWD/MTU rod average discharge burnup.

High discharge burnups reduce total fuel cycle costs. In particular, they permit the design of a three-batch core, even for longer fuel cycles. The savings in fuel cycle costs is estimated to be 2 to 4%. In addition, higher discharge burnups result in a significant reduction in the number of discharged fuel assemblies per annum and at the end of the 60 year plant life, thereby reducing spent fuel storage and disposal costs.

4. SYSTEM 80® FUEL MANAGEMENT DATA

The equilibrium cycle fuel management for the System 80® plant for Asia is a three-batch loading scheme with six sub-batches in the reload batch. The core thermal power output is 2951 MWth, and the fuel cycle length is eighteen (18) months. With the use of Turbo™ fuel, all rods contain a top and bottom reduced-enrichment uranium axial blanket to improve fuel cycle economics. Also, the erbium burnable absorber rods contain cutback regions at the top and bottom of the rods.

The details of fuel management are provided in Tables 1 through 3, and Figure 2. Table 1 summarizes some important plant and fuel management parameters. Tables 2 and 3 provide core loading and fuel rod loading, respectively. Figure 2 shows the fuel loading scheme and fuel shuffle pattern.

The fuel and core design presented includes all of the design features described in Sections 2 and 3, thus providing a low-cost design with proven design features which meets thermal margin and other design requirements.

Table 1 Equilibrium Cycle Design for System 80® Plant and Fuel Management Parameters

Fuel Management Parameter	**Value**
Core Power (MWth)	2951
Plant Power (MWe)	1100
Core Flow Rate (Lbs/hr)	123.8×10^6
Nominal Reactor Vessel Inlet Temperature, °F	559
Nominal Reactor Vessel Outlet Temperature, °F	615
Cycle Length (Effective Full Power Days (EFPD))	477
Cycle Length (Months)	18
Cycle Maximum Radial Peaking Factor (Fr)	1.61
Total Number of Fuel Assemblies	177
Number of Fresh Feed Fuel Assemblies Per Reload	60
Total Number of Erbium Burnable Absorber Rods Per Reload	1344
Batch Average Enrichment (w/o U-235)	4.6
Maximum Discharge Burnup, Rod Average (MWD/MTU)	65,000
Cycle Maximum Critical Boron Concentration @ HFP (ppm)	1850
End of Cycle Boron Concentration (ppm)	10

Table 2 Equilibrium Cycle Design for System 80® Core Loading Summary

Batch ID	Number of Assemblies	BOC Burnup, MWD/MTU	EOC Burnup, MWD/MTU
Z0	28	0	21754
Z2	8	0	24550
Z3	8	0	25585
Z4	4	0	24441
Z5	4	0	25875
Z6	8	0	26238
Y0	28	21754	41801
Y2	8	24550	44851
Y3	8	25585	45723
Y4	4	24441	34082
Y5	4	25875	47684
Y6	8	26238	47629
X0	28	41801	55275
X2	8	44851	50407
X3	8	45723	52804
X4	4	34082	42289
X6	8	47629	57833
W4	1	42289	60175

Batch Z: Fresh Fuel
Batch Y: Once Burned Fuel
Batch X: Twice Burned Fuel
Batch W: Thrice Burned Fuel

Table 3 Equilibrium Cycle Design for System 80® Fuel Rod Loading Summary

		Fuel Rod Inventory			
Batch ID	Number of Assemblies	# Rods (U enrich low)	# Rods (U enrich high)	#Er Rods (U enrich low)	wt.% Er
Z0	28	52	184	-	-
Z2	8	60	152	24	2.1
Z3	8	52	152	32	2.1
Z4	4	44	152	40	2.1
Z5	4	36	152	48	2.1
Z6	8	24	144	68	2.1

Note: All rods have a 7 inch blanket region of reduced enrichment (2.5 wt.%) at the top and bottom. This blanket region does not contain any erbium burnable absorber.

Assembly No. Subbatch.
Prev-Location

					01 X6 21	02 X3 13	03 Y4 25
			04 X2 24	05 X0 27	06 Y0 16	007 Z0	08 Z0
		09 X4 45	10 Z0	11 Z0	12 Z2	13 Y3 20	14 X6 36
	15 X2 18	016 Z0	17 Y0 46	18 Y2 31	19 X0 35	20 Z3	21 Y6 51
	22 X0 41	23 Z0	24 Y2 12	25 Z4	26 X0 06	27 Y0 23	28 Z6
29 X0 17	30 Y0 10	31 Z2	32 X0 42	33 X0 30	34 Z5	35 Y0 07	36 Y6 49
37 X3 39	38 Z0	39 Y3 40	40 Z3	41 Y0 11	42 Y0 38	43 Y5 34	44 Z6
45 Y4 25	46 Z0	47 X6 36	48 Y6 51	49 Z6	50 Y6 49	51 Z6	52 W4 09

Figure 2 Equilibrium Cycle Design for System 80® Fuel Loading/Shuffling Pattern

5. THERMAL MARGIN ENHANCEMENTS

The System 80® design that is offered to Asia is similar to the reference System 80® plant (Ulchin Units 3 and 4), but includes several features that increase thermal margin. These features are in use in ABB CE plants in the U.S., or are based on methodology improvements that have been licensed by the U.S. Nuclear Regulatory Commission (NRC). These margin-improving enhancements: erbium integral absorbers, Turbo Zircaloy mixing grids, reduced reactor inlet and outlet temperatures and improved Appendix K LOCA methods are described below.

The erbium integral absorber is described in detail in Section 2.1. An 8% improvement in DNB overpower margin is estimated relative to using Gadolinia.

The Turbo Zircaloy mixing grid is described in detail in Section 2.5. A 10 to 15% improvement in DNB overpower margin is estimated with the Turbo™ mixing grids based on critical heat flux tests.

Reduced inlet temperature reduces the core and hot channel coolant quality, which directly impacts the calculated critical heat flux expressed as the Departure from Nucleate Boiling Ratio (DNBR). Alternatively, this temperature reduction can be expressed as the increase in core power margin to reach an operating or trip limit. The CE-1 critical heat flux correlation predicts an increase in core power margin of approximately 4 percent resulting from the 6°F decrease in reactor inlet temperature for the System 80® plant design for Asia relative to the reference System 80® plant design. In addition, the System 80® reactor coolant pumps are nearly constant volume displacement pumps. As a result, the reduction in core inlet temperature increases the coolant density resulting in a higher core coolant mass flow rate at the same volume flow rate. This provides an additional 1% increase in thermal margin.

The reference System 80® plant (Ulchin Units 3 & 4) use a conservative evaluation of heat transfer during reflood. The System 80® plant offered to Asia removes that conservatism, resulting in a significant gain in the maximum allowable peak linear heat generation rate, thereby providing a substantial increase in linear heat rate (LHR) thermal margin (~10%).

6. THERMAL MARGIN ASSESSMENT

ABB CE has performed a thermal margin assessment of the System 80® equilibrium fuel management described in Section 3.0. This assessment is done in a form similar to that specified in the EPRI Advanced Light Water Reactor (ALWR) Utility Requirements Document (URD) (Reference 5), in which four aspects of thermal margin are considered as shown in Figure 3.

6.1 Rated Power

The limiting power parameter required to operate the plant at 100% power in a normal, equilibrium mode is determined. In ABB CE plants, this limiting power parameter is either the peak linear heat rate (LHR) or the minimum DNBR. Both LHR and DNBR margin requirements change during the cycle as the core peaking changes with burnup. Thus, it is necessary to evaluate the peak LHR and minimum DNBR throughout the cycle.

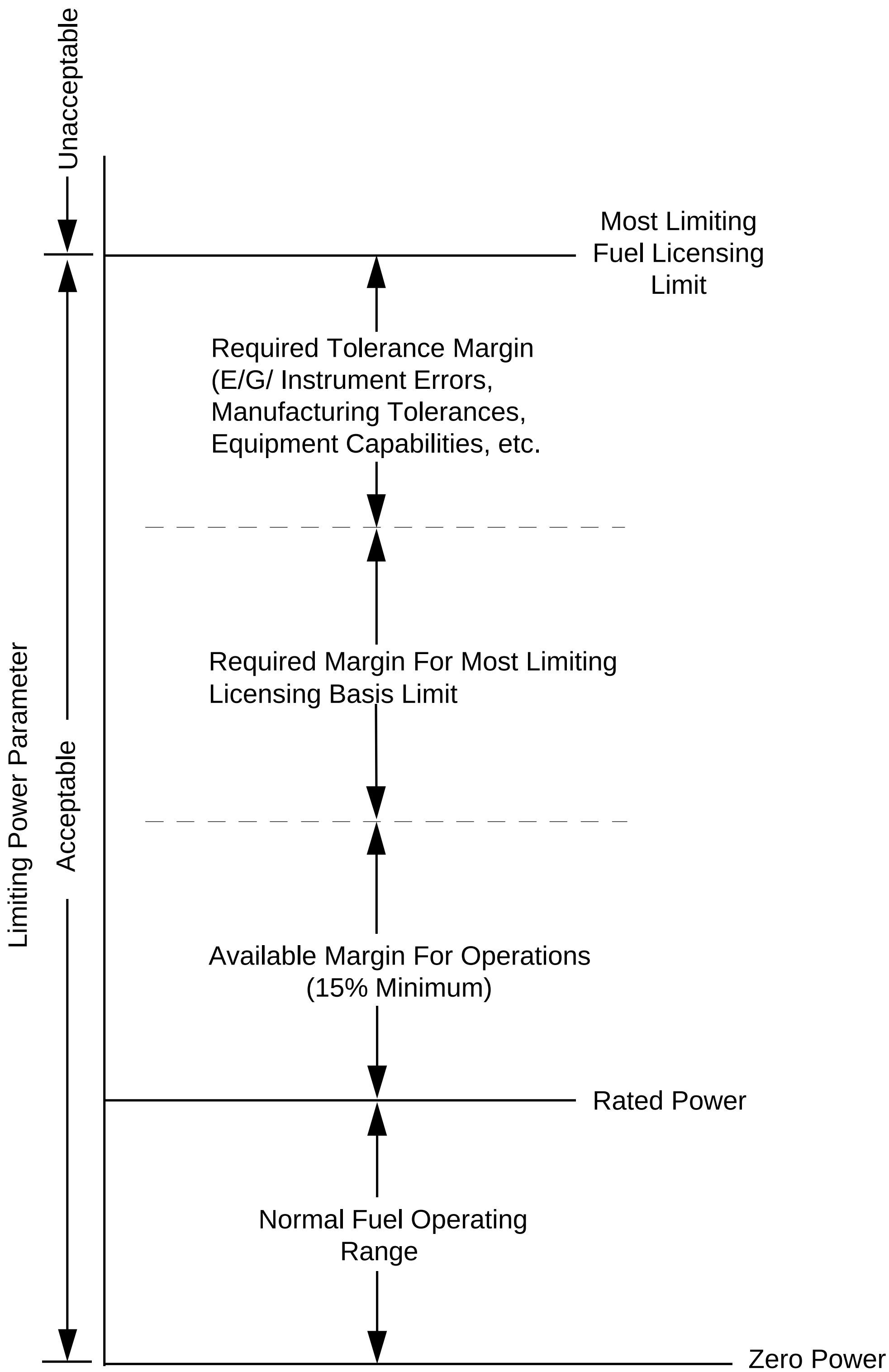

Figure 3 Fuel Thermal Margin

6.2 Required Margin for Most Limiting Licensing Events

The thermal margin needed to accommodate the most limiting licensing event is determined. Large break Loss of Coolant Accident (LOCA) is typically the LHR event, whereas there are several candidates for the limiting DNBR event. ABB CE has successfully developed and licensed many improvements to the methodologies used to evaluate potentially limiting events, thus reducing required margin.

6.3 Required Margin for Tolerances

The thermal margin required to accommodate tolerances is determined. Tolerances may involve as-built dimensions, changes in plant or fuel during operation (e.g., rod or assembly bow), and measurement tolerances and drift (e.g., reactor coolant system flow, temperature, and pressure), and uncertainties associated with operation of the protection system. These uncertainties are minimized by the use of a Core Protection Calculator (CPC) in the System 80® plant. The CPC is a digital protection system used in all modern ABB CE 16x16 plants. It is the only digital protection system approved by the US NRC. ABB CE also has been the world leader in developing and licensing the statistical combination of uncertainties (SCU) methodologies that significantly reduce the margin required to accommodate tolerances and measurement uncertainties.

6.4 Available Margin for Operations (15% Minimum)

As specified in the EPRI ALWR URD, the System 80® fuel management provides a minimum of an additional 15% margin, beyond the margin necessary to accommodate limiting licensing basis events and tolerances, which is available for operations at all times in the cycle.

The evaluation of thermal margin for System 80® is performed through an analysis that explicitly models changes to core radial and axial power distributions during operation. The results of the evaluation demonstrate that the System 80® equilibrium fuel management has sufficient thermal margin on both LHR and DNBR to fully comply with the requirements of the EPRI ALWR URD, including the 15% overpower margin at all times in the cycle.

The NSSS design, fuel management design and engineering methods proposed for the System 80® plant for Asia differ somewhat from those for the reference System 80® plant (Ulchin Units 3&4). Table 4 identifies the major differences between the two plant designs, together with an estimate of the resultant impact on thermal margin. With these design and analysis methodology differences, the System 80® plant offered to Asia will fully satisfy the EPRI ALWR URD requirements regarding thermal margin.

7. SUMMARY

The fuel management for the System 80® design proposed for Asia incorporates the advanced Turbo™ fuel design features, fuel management features, and thermal margin enhancements utilized in ABB CE reactors currently operating throughout the world. In addition, those improvements that are now undergoing development for near-term implementation in their reactors, have been included in the proposed design. This approach ensures that the Asian market will be able to rely on the vast experience of ABB CE and its customers, thereby enabling the most advanced proven fuel and fuel management designs possible. This will result in the lowest cost, highest availability and greatest thermal margin core design.

Table 4 Thermal Margin Impact of Design Differences Between Reference System 80® Plant and Asia System 80® Plant

Characteristic	Reference Plant (Ulchin 3&4)	Proposed Asia Design	Impact on Thermal Margin, DNB	Impact on Thermal Margin, LHR
Core Power Level (MWth)	2815	2951	(5%)	(5%)
Reactor Inlet and Outlet Temperatures (°F)	565 / 621	559 / 615	5%	nil
Burnable Absorber	Gd	Er	8%	8%
Axial Blankets	No	Yes	(2%)	(2%)
Cycle Length	12 Month	18 Month	(5%)	(5%)
Turbo™ Mixing Grid	No	Yes	10% to 15%	nil
LOCA Methods	Standard LOCA Methods	Improved LOCA Methods	nil	+10%
Design Overpower Margin (DNBR)	8%	15%	(7%)	-
Design Overpower Margin (LOCA)	15%	15%	-	nil

8. REFERENCES

1. Jonsson, Alf, "Comparison of the Economic Performance of Burnable Absorbers for 17x17 PWR Fuel," Advances in Nuclear Fuel Management II, Myrtle Beach, SC, March 23-26 1997, Vol. 1, p.7-25.
2. Dixon, David J., "Optimum Fuel Pellet Diameter Considerations," presentation to ANS, June 12, 1981.
3. Jonsson, Alf, "Optimum Fuel Rod dimensions," ANS Winter Meeting, Albuquerque, NM November 15-21, 1997.
4. Karoutas, Zeses E., "Supporting Test Data and Analysis for ABB CE's Turbo™ PWR Fuel Design," presentation 12th annual KAIF/KNS meeting in Seoul Korea, April 3 & 4, 1997.
5. "Advanced Light Water Reactor Utility Requirements Document" Volume II ALWR Evolutionary Plant Chapter 4 Reactor Systems Revision 6, Issued December 1993.

9. KEY WORDS

Advanced fuel, thermal margin, fuel reliability, mixing grids, fuel management, high burnup.