AN INVESTIGATION OF AXIAL XENON STABILITY IN VVER-1000 REACTOR DESIGNS

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It has been reported [1] that nuclear plants of the VVER-1000 design have experienced frequent xenon oscillation control problems. In most PWRs, xenon oscillations are largely a problem in the axial direction. Radially, PWRs tend to be very stable relative to xenon oscillation. Axial Xenon oscillations as a minimum cause operational problems requiring frequent operator intervention to control the oscillation and increased duty on the various control mechanisms (Control rod and soluble boron systems). In more severe cases, these oscillations can cause power reductions (or plant trips) due to high core peaking factors, thereby reducing overall plant capacity factors. In the worst case, uncontrolled xenon oscillations can lead to fuel damage from either pellet clad interaction (PCI), DNB failure or fuel centerline melting if the plant does not have adequate safety system protection for tripping the plant on high local core peaking factors resulting from highly skewed axial power distributions.

From a basic core design viewpoint it is not obvious why VVER-1000 design reactors should be significantly different from typical western reactors. Table 1 compares global VVER-1000 core parameters to those of typical Westinghouse design 3 and 4 loop cores.

In addition, global core reactivity parameters such as moderator temperature coefficients, boron worths, and power defect are comparable to western designs. Therefore, one would not expect the behavior of the axial xenon distribution to be significantly different either. In fact, Reference 2 indicates that the axial stability index of the VVER-1000 designs is indeed similar to western designs.

Table 1
Comparison Of Basic Core Parameters

	Westinghouse		VVER-1000
Thermal Power (MW)	2775	3411	3000
Number Of Loops	3	4	4
Number Of Assemblies	157	193	163
Core Equivalent Diamter (m)	3.04	3.37	3.24
Core Active Fuel Height (m)	3.66	3.66	3.53
Core Volume (m^3)	26.6	32.6	29.1
Core Unranium Loading (MTU)	67-72	82-88	74.3
Core Power Density (kw/l)	105	105	103
Core Specific Power (kw/kg)	38-41	38-41	40
Core delta T, °C	36	36	30.3

If the axial xenon distribution is no more unstable than in western plants, what is the cause of the xenon oscillation problems? Reference 3 indicates that the control rod worths of the VVER-1000 designs are somewhat lower than is typical of Westinghouse designed core. In addition, there is very little overlap of the individual control banks. In would therefore appear that the control rod worth and overlap were optimized to minimize the effect of the control rods on the axial power distribution and therefore reducing the possibility of the rods initializing a xenon oscillation. However, once an oscillation begins, such a control rod system is very ineffective at controlling the oscillation.

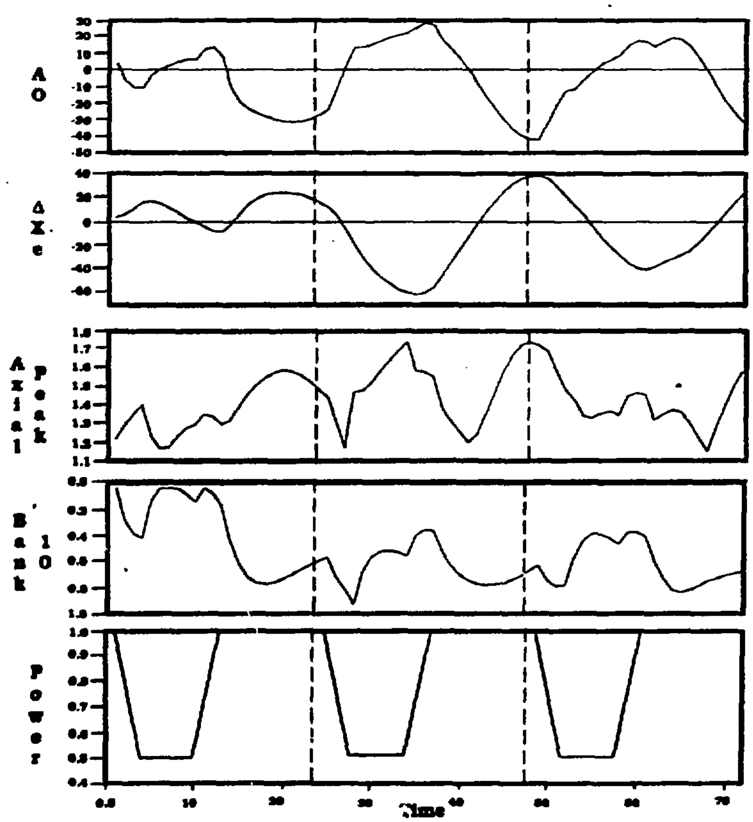
Finally, as indicated in Reference 3, a power distribution control strategy that controls the core axial power distribution skewing as indicated by the parameter axial offset (AO) is only now being developed.

To examine the controllability of the current design, we first set up one dimensional core model representative of the VVER-1000 design. This model was then used to evaluate core behavior during typical power change maneuvers that result in non-equilibrium xenon conditions. Figure 1 shows the how the lack of a power distribution control strategy combined with the low worth control banks influence power distribution control. Figure 1 shows a typical daily load follow cycle for three days where core power is reduced to 50% power during the night. During this maneuver no attempt was made to control or limit the core power distribution. Shown in the figure are core power level, control rod insertion, axial offset, the core axial peaking factor

FIGURE 1

VVER-1000

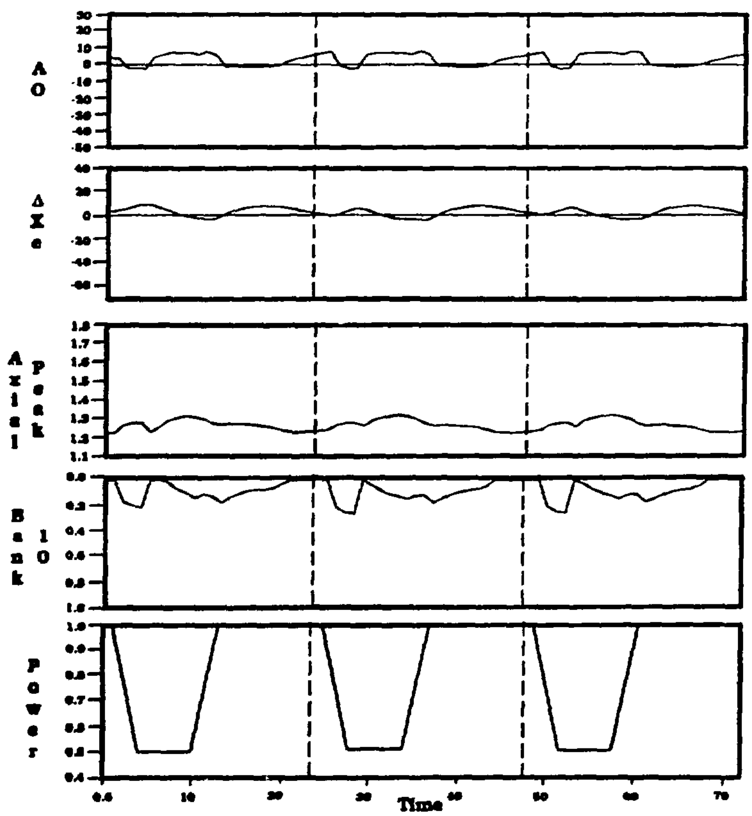
LOAD CHANGE WITH NO AXIAL POWER DISTRIBUTION CONTROL AND CURRENT CONTROL ROD SYSTEM



and a measure of the core axial xenon distribution called Delta-xenon. Delta xenon is defined as the difference in xenon distribution in the top half of the core minus the bottom half of the core. As can be seen in the figure, the power change combined with control rod motion set off a large axial xenon oscillation as indicated by delta-xenon, resulting in large swings in the core axial offset further resulting in axial peaking factors as high as 1.7. While high axial peaking factors are acceptable if the corresponding radial peaking factors are low, current fuel designs and loading pattern concepts would not typically allow axial peaking factors at full power greater than about 1.3 - 1.4. Therefore it is unlikely that this operation would be acceptable in actual plant operation.

An investigation of possible improvements to this design was made. To make improvements in the controllability of the reactor, control rod overlap was set to be more typical of current Westinghouse plants [4]. In addition, the Westinghouse Constant Axial Offset Control Strategy (CAOC) [5] was used. Figure 2 shows the same three days of load follow operation using these changes. As can be seen, Figure 2 indicates that these changes result in very stable core xenon behavior with little deviation of the core axial power distribution from it's equilibrium value of AO with correspondingly low axial peaking factors.

FIGURE 2
VVER-1000
LOAD CHANGE WITH AXIAL POWER DISTRIBUTION CONTROL AND IMPROVED CONTROL ROD OVERLAP



In conclusion, there is no indication that xenon oscillations are an inherent problem in the VVER-1000 core design. Simple changes to the control rod system coupled with a sound power distribution control strategy that has been proven to be an effective but simple procedure to follow eliminate xenon control problems. Further, a protection system that uses AO as an input to the trip signal to reduce the power level at which the plant trips as the absolute value of AO becomes large will assure more safe plant operation in the case that a large xenon oscillation does occur. The changes described in this paper can be implemented in a very cost effective manner. There are no equipment changes needed, existing control rods can be used. Only software changes (control rod overlap, AO band limits) and associated Technical Specifications and procedure changes are required. Basic core monitoring only requires the use of two section EXCORE detectors to monitor AO, although significant benefits can be obtained through the use of continuous three-dimensional core monitoring, using the VVER-1000 fixed incore detectors in conjunction with state of the art software such as the BEACON system (6).

The simulations presented did not make use of the part length control rods existing in the VVER-1000 designs. These part length rods should be removed and replace with full length control rods. This would provide the plant with additional shutdown margin. Additional benefits can be obtained by using multiple banks of control rods moving independently. Such a design is the Westinghouse MSHIM[7] system designed for the AP600. The use of an MSHIM system would eliminate the need for boron concentration changes during load following type maneuvers and at the same time automate control of the axial power distribution.

References

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