RECENT CORE DESIGN AND OPERATING EXPERIENCE IN LOVIISA NPP

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ABSTRACT

This paper demonstrates the recent years experience in core design and operating in the Loviisa NPP. The two units of Loviisa NPP are run with reduced core and 1500 MW power. Both units are currently in nearly equilibrium 3-batch fuel cycle. Two different fuel types are used: first unit (Loviisa-1) runs with BNFL fuel whereas TVEL fuel is used in the 2nd unit (Loviisa-2).

The paper demonstrates recent core loading patterns together with a short discussion on their properties. Main properties of the two used fuel types are shortly described. The major part of the presentation consists of comparison of measured and computed core characteristics for TVEL and BNFL fuel. Comparison is performed for a couple of recent cycles at both units.

An insight into future challenges of core loading pattern design at Loviisa NPP is also given. This includes plans to shift from current 3-batch loading to 4-batch loading, which means increased enrichment and burn-up.

1. INTRODUCTION

The two units of Loviisa NPP are run with reduced core on 1 500 MW thermal power. Loviisa-1 runs in nearly equilibrium cycle with 3.7 ... 3.8 % enriched Westinghouse (former BNFL) fuel and Loviisa-2 in nearly equilibrium cycle with 4.0 % enriched TVEL fuel. Partly low-leakage loading patterns are being used at both units.

In this paper Section 2 summarizes present core limitations and properties of currently used fuel types. Section 3 demonstrates recent core loading patterns together with their properties at both NPP-units. Section 3 also includes boron curve data and a comparison of measured and calculated assemblywise power distributions. This comparison gives interesting information about fuel-type-specific properties of the core. Comparison also clearly demonstrates certain uncertainty trends in the used modelling and computing tools.

Future plans of loading pattern design at Loviisa NPP are discussed in the Section 4. Section 5 summarizes the main observations of preceding results.

2. FUEL TYPES AND CORE LIMITATIONS

As noted above, Loviisa-1 is currently running with Westinghouse fuel and Loviisa-2 with TVEL fuel. The slightly differing properties of these fuels types are: mass of uranium and consequently enrichment, cladding thickness and upper flow plate flow area geometry.

According to CFD-calculations the different upper flow plate flow area geometry in Westinghouse fuel causes somewhat less mixing in the assembly outlet flow as compared to TVEL fuel. This should have an effect on the interpretation of the temperature measurements into assembly power distribution particularly in mixed cores with different fuel types. In cores with only one fuel type the effect (common bias) is eliminated in power distribution comparisons due to normalization.

The main properties of the two used fuel types are summarized in the Table 1.

Table 1. Main parameters of different fuel types used in Loviisa.

		TVEL			Westinghouse	
		"36Z"	"40Z"	"40T"	"37N"	"38N"
Shroud box						
material		Zr2.5%Nb	Zr2.5%Nb	Zr2.5%Nb	Zircaloy-4	Zircaloy-4
wall thickness	mm	1.5	2	1.5	1.6	1.6
dim. across flats	mm	144.2	144.2	1.5	144.3	144.3
Fuel rods						
cladding material		Zr1%Nb	Zr1%Nb	Zr1%Nb	Zircaloy-4	Zircaloy-4
outer diamater	mm	9.1	9.1	9.1	8.9	8.9
cladding thickness	mm	0.7	0.7	0.7	0.55	0.55
rod pitch	mm	12.2	12.2	12.3	12.3	12.3
Rod bundle						
U-mass	kg	119.7	115.9	120.9	125.9 (fixed) 120.7 (follower)	125.9 (fixed) 120.7 (follower)
enrichment	%	3.6	4.0	4.0	3.7	3.8
profiling		no	no	no	no	no

The core limitations define the permissible initial states of the core which are also assumed in the safety analyses. The most important core limitations in practice for Loviisa NPP are:

- Maximum allowed average assembly burn-up of 45 MWd/kgU. This corresponds to maximum rod burn-up of approximately 53 MWd/kgU.

- Maximum allowed local linear heat rate of 325 W/cm. This originates from the assumptions made in the analysis of large LOCA. A safety factor of 1.12 is included in the calculated values to account for different uncertainties and tolerances. The linear heat rate limit is decreasing with burn-up.

- Maximum allowed subchannel outlet temperature of 325 °C. A safety factor of 1.16 for the enthalpy rise is included in the calculated values to account for different uncertainties and tolerances.

A more detailed description of core limitations for Loviisa can be found in Ref. /2/ and for Finnish NPPs in general also from the STUK YVL-guides /3/.

3. CORE OPERATING EXPERIENCE

3.1 Loading patterns

In both units of Loviisa NPP a partly low-leakage loading patters are being used. *Figure 1* and *Figure 2* illustrate loading patterns for the latest cycles. Loviisa-1 is almost entirely loaded with Westinghouse fuel and Loviisa-2 with TVEL fuel. This fact allows making easily a comparison between computed and measured assembly power distributions. Also correlation of observed deviations between the two different reactors with different fuel types can be studied.

3.2 Boron curves

Boron curves for the latest cycles and both units are represented in the *Figure 3* and *Figure 4*. Our experience from Loviisa is that -3 % burn-up adjustment is required to fit the calculated cycle length with actual plant measurements. This means, that the two group data Σ_x is taken with 3 % lower burn-up in the HEXBU code. The effect of the adjustment is 3 % increase in the equilibrium cycle length. The same adjustment is used for both fuel types.

3.3 Assembly power distributions

Figure 5 and *Figure 6* illustrate comparison of measured and computed assemblywise thermal power at BOC state. The traditional assembly power measurement is based on the assembly outlet thermo-couple. A fully mixed flow is assumed which, according to present-day knowledge, is not the case in reality. However, since the whole core practically consists of assemblies of the same type, a potential small bias due to incomplete mixing before the thermocouples reduces out when the measured power distribution is normalized to core power. The core inlet temperature is determined as an average of cold leg temperatures. Computed assembly power values, for one, are results of computation by HEXBU-3D/MOD5 code. This comparison shows a rather good agreement between measurements and computed values the RMS deviations being 3.0 % and 2.1 % and maximum deviations 6.0 % and 5.4 % for Loviisa-1 and Loviisa-2, respectively.

For a long time we have observed that there is a certain trend how the deviation between measured and calculated power distribution evolves from BOC to EOC. This is illustrated in *Figure 7, …, Figure 10,* where the difference between EOC and BOC deviation is plotted. The figures show that from BOC to EOC the deviation changes to negative direction in the inner part of the core and to positive direction in the outer part of the core. This drift phenomenon is practically independent of fuel type being only slightly weaker in Loviisa-2 than in Loviisa-1.

The phenomenon is a systematic uncertainty in the predicted power distribution. The root cause behind the observed phenomenon has been under thorough investigation but we are not yet ready to make final conclusions.

An interesting detail is location 11 in LO2 C27 (*Figure 2*). There is a single symmetric location loaded with Westinghouse fuel in otherwise TVEL core. The deviation between measured and calculated assembly power is practically equal as for the fresh TVEL-assemblies in locations 21 and 14 as can be seen in the *Figure 6*. In this comparison the interpretation of the thermocouple measurements (YQ30T) is identical for both assembly types. Consequently the power distribution comparison suggests that the deviations in assembly outlet flow mixing properties (flow plate) are small or there are compensating effects (assembly flow, deviation in calculated power) which cancel the differences in assembly outlet flow mixing properties.

Based on the measured flow resistance values of the assembly types, the assembly flow in mixed core should be within 1 % for the two fuel types. According to the CFD-calculations /3/ the difference in measured enthalpy rise peaking factor (K_{TC}) with equal flowrate is less than 4 % (TVEL $K_{TC} \approx 1.01$ and Westinghouse $K_{TC} \approx 0.97$).

The measured bypass flow fraction is calculated from independently measured net flow rate and total flow rate. Net flow is based on the information from core outlet thermocouples and plant thermal power from secondary side. Total flow is based on the measured pressure differences across the steam generators. Based on the observed bypass flow fraction the difference in measured enthalpy rise (δK_{TC}) is ≈ 2 % (LO2/LO1). This supports the results of the CFD-calculations that the measured enthalpy rise with TVEL assemblies is somewhat higher. The difference, however, seems to be less than predicted. Based on this data and our earlier evaluations it seems that the real effect is 70...80 % of the predicted δK_{TC} effect. The compatibility of the TVEL and Westinghouse assemblies in mixed core is good.

3.4 Fuel mechanical behaviour

The fuel mechanical behaviour in Loviisa has been extremely good with both fuel types during the past eight years. No fuel leaks have been observed since 1999. With Westinghouse fuel no leaks has occurred up to now. First reload of this fuel type was loaded into the core of Loviisa-1 in 2001.

Normal fuel residence time in the reactor is three cycles and partly four cycles. Some test assemblies of both fuel types has been irradiated for five cycles to get experience of fuel behaviour with higher burn-up in normal operation.

4. FUTURE PLANS

The operating license has recently been renewed for both units targeting to 50 year lifetime: Loviisa-1 to the end of 2027 and Loviisa-2 to the end of 2030.

According to new fuel contract fuel to the Loviisa NPP will be supplied by TVEL from 2008 on to the end of plant lifetime.

Our plan is to change from the current 3-batch loading pattern to 4-batch loading pattern. This requires licensing of higher burn-up limit /2/. Our target is 55 MWd/kgU for maximum assembly average burn-up (current 45 MWd/kgU). Higher burn-up means higher enrichment and this in turn means that burnable poison (Gd) has to be used, mainly to meet the criticality

safety requirements of the fuel handling systems. First reload of new fuel with higher enrichment is expected to be loaded in 2009.

5. CONCLUSIONS

Loviisa-1 is currently in nearly equilibrium cycle with Westinghouse fuel and Loviisa-2 in nearly equilibrium cycle with TVEL fuel. According to new fuel contract fuel to the Loviisa NPP will be supplied by TVEL from 2008 on to the end of plant lifetime, 2027 for Loviisa-1 and 2030 for Loviisa-2.

Core operational experience has been according to expectations. Some systematic trends in the deviation between measured and calculated assembly power distribution can now be clearly observed with both fuel types in nearly equilibrium core. The root cause behind the observations is still under investigation.

The fuel mechanical behaviour in Loviisa has been extremely good with both fuel types during the past years.

Change from the current 3-batch loading pattern to 4-batch loading pattern is expected to begin in 2009. Licensing of higher burn-up limit is required.

REFERENCES

/1/ Antila M., Kuusisto J.: *Core design and operating experience using new fuel types at uprated power in Loviisa NPP*. 14th AER Symposium on VVER Reactor Physics and Reactor Safety, 13-17 September 2004, Espoo Finland.

/2/ Finnish radiation and nuclear safety authority (STUK). YVL 6.2:
Design bases and general design criteria for nuclear fuel. November 1, 1999.
<http://www.stuk.fi/saannosto/YVL6-2e.html>

/3/ Toppila T., Lestinen V.: *CFD simulation of coolant mixing inside the fuel assembly top nozzle and core exit channel of a VVER-440 reactor.* 14th AER Symposium on VVER Reactor Physics and Reactor Safety, 13-17 September 2004, Espoo Finland.

FIGURES

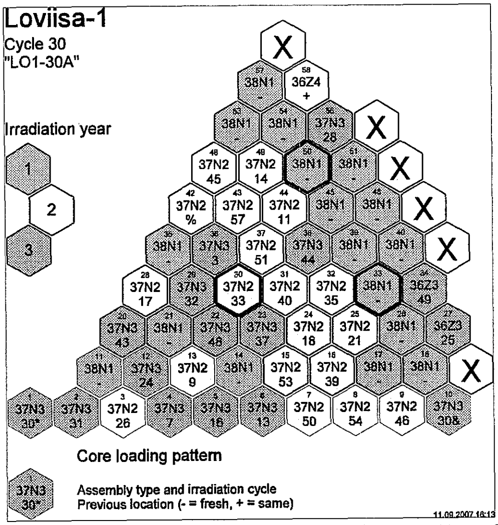

Figure 1. LO1 C30 core loading pattern. Assembly type coding is eeNm, where ee = enrichement coding, N = Westinghouse, Z = TVEL, m = irradiation cycle.

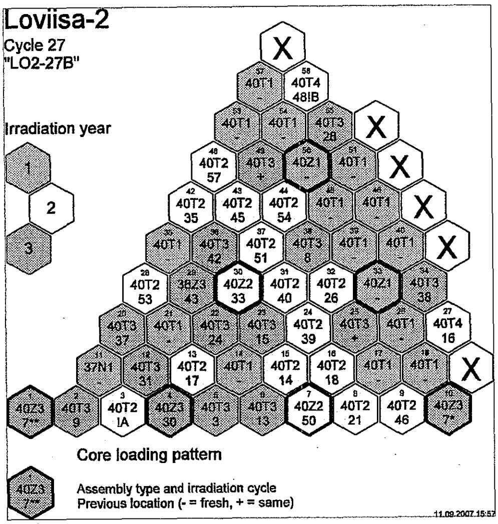

Figure 2. LO2 C27 core loading pattern. Assembly type coding is eeNm, where ee = enrichement coding, N = Westinghouse, T or Z = TVEL, m = irradiation cycle.

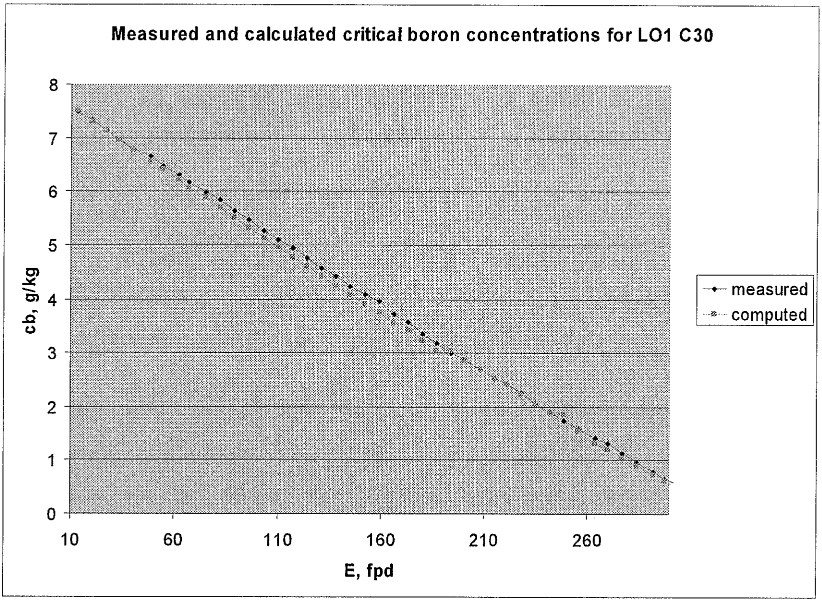

Figure 3. Measured and calculated critical boron concentrations for LO1 C30.

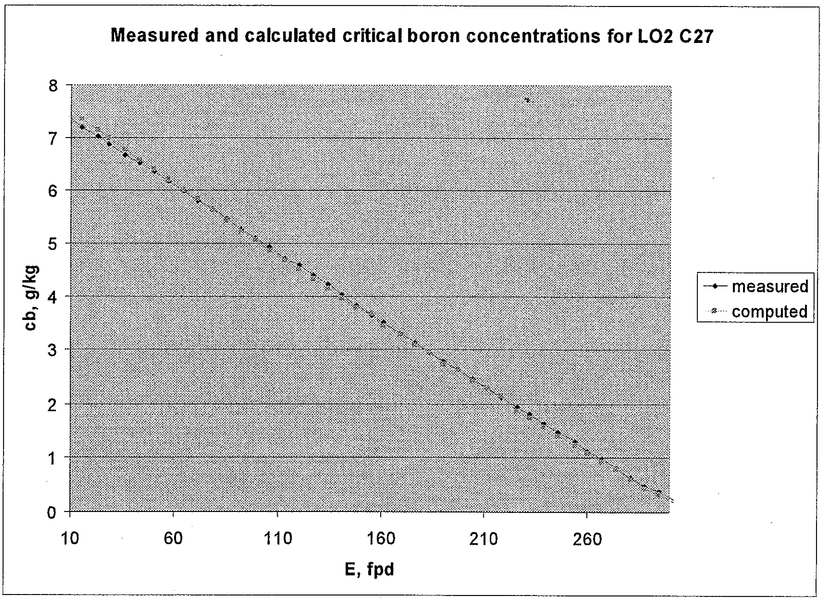

Figure 4. Measured and calculated critical boron concentrations for LO2 C27.

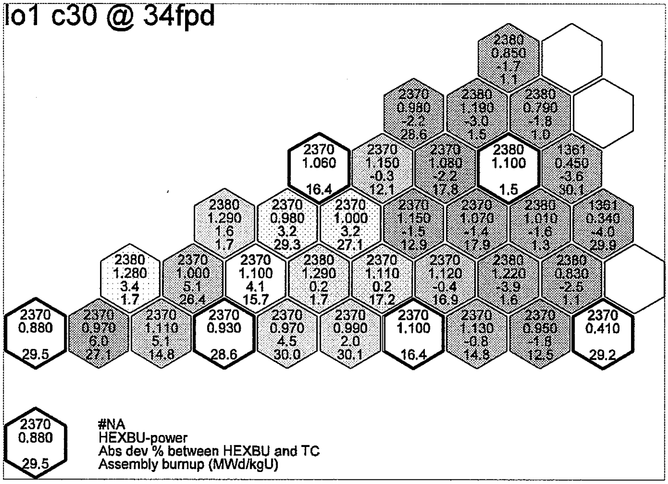

Figure 5. LO1 BOC30, comparison of measured and calculated assembly powers. A fully mixed coolant flow at TC is assumed. Assembly type coding is neex, where n = 1 for TVEL, n = 2 for Westinghouse, ee = enrichment, x = assembly type number.

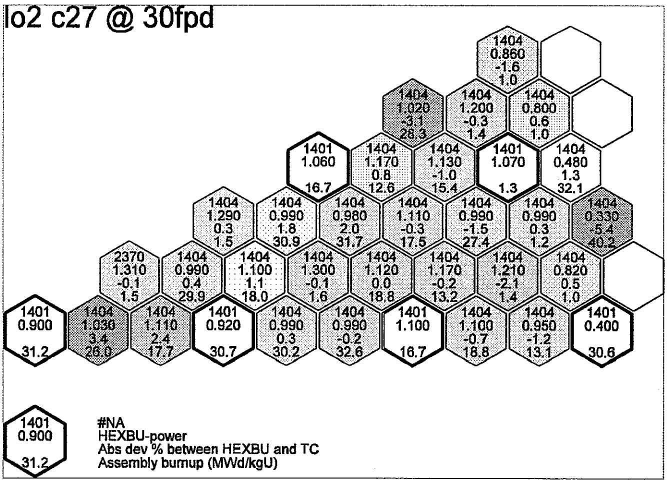

Figure 6. LO2 BOC27, comparison of measured and calculated assembly powers. A fully mixed coolant flow at TC is assumed. Assembly type coding is neex, where n = 1 for TVEL, n = 2 for Westinghouse, ee = enrichment, x = assembly type number.

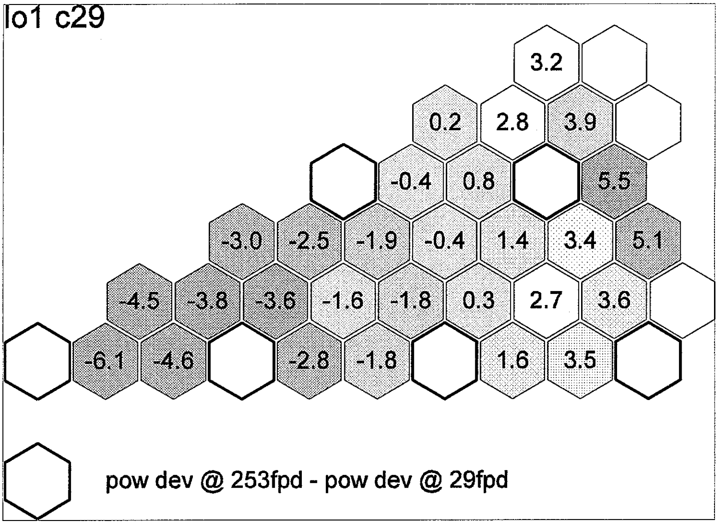

Figure 7. LO1 C29, difference in EOC and BOC assembly power deviations.

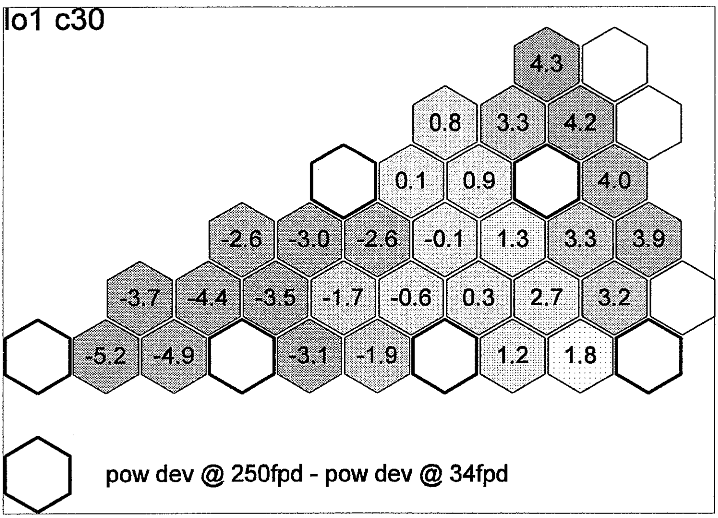

Figure 8. LO1 C30, difference in EOC and BOC assembly power deviations.

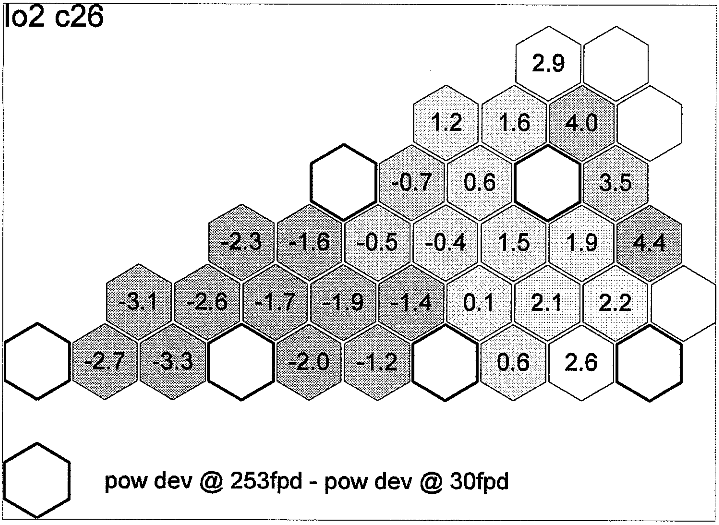

Figure 9. LO2 C26, difference in EOC and BOC assembly power deviations.

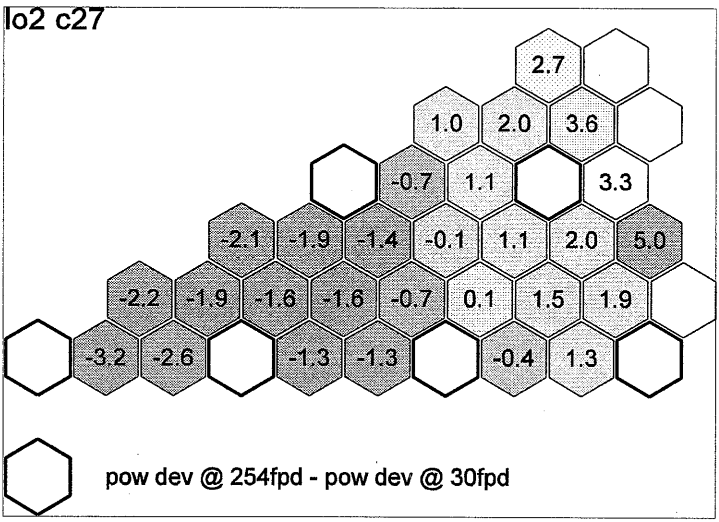

Figure 10. LO2 C27, difference in EOC and BOC assembly power deviations.