ROP TRIP SETPOINTS UPDATE FOR GENTILLY-2 SINCE 2004

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Abstract

Since the last ROP analysis documented in TTR-753 reference, a significant number of measurements of the pressure-tube internal diameters in Gentilly-2 has been done. This brought to 62 the number of Gentilly-2 pressure tubes for which the internal diameters have been measured.

Evaluation of the diametral strains obtained from these measurements, as compared to the diametral strains predicted by the equation RC-1980, concluded that for the majority of the pressure tubes evaluated, the diametral creep strain rate is lower than that predicted by the equation RC-1980. Thus, the average ratio between measured and calculated maximum deformations is equal to 0.84 with 0.096 as a standard deviation. The last analysis used an average ratio between measured and calculated maximum deformations equal to 0.9188 with 0.1836 as a standard deviation.

There are other changes that impact on the ROP base trip setpoints: the revision of the ROP trip setpoint uncertainties used in ROVER-F, the revision of flux shapes and the modifications of the ROP system during the 2005 plant outage.

In addition, due to Primary Heat Transport System (PHTS) aging, revision over time of ROP base trip setpoints is required to ensure effectiveness.

The methodology of the analyses is the same as in the last analysis documented in TTR-753 and it consists of:

- creating a revised PHT circuit model for NUCIRC to include up to date measurements of HTS conditions,
- calculating the Critical Channel Power (CCP) with NUCIRC at three points in time, 6211, 6800 and 7300 EFPD (Equivalent Full Power Days) based upon plant aging models including the measured diametral creep rates, and
- calculating ROP trip setpoints using ROVER-F for each of the three subsequent core ages and for 51 limiting ROP flux shapes.

The calculations at the three points in time, 6211, 6800 and 7300 EFPD, resulted in a new trend in the ROP base trip set points as a function of EFPD that is at least 2.5% higher compared to the actual trend from the last ROP analysis (TTR-753). In addition, this new trend in the ROP base trip set points varies according to a quadratic curve that decreases at a reduced rate than the one documented in the last ROP analysis (TTR-753).

1. Introduction

Gentilly-2 [2,10] has introduced since 1999 a correction to the ROP setpoints to account for the impact of Primary Heat Transport System (PHTS) ageing. According to this methodology, the correction to ROP base trip setpoints need to be periodically revised to ensure that the Regional Overpower Protection (ROP) system remain effective for changes seen in the PHTS aging trends or to account for new information coming from new pressure tube diametrical strain measurements.

Since the introduction of the ageing correction, two ROP analysis have been submitted to and approved by the CNSC [1,10]. Since the last ROP analysis for G2 PHTS, documented in TTR-753 [1], a significant number of measurements of the pressure-tube internal diameters in Gentilly-2 has been done. The number of measurements have been increased from 21 inspections for 12 pressure tubes to 81 inspections covering 62 pressure tubes (PT). The analysis of the complete set of measurements shows that the PT diametral creep rates at G2 are lower than that assumed to derive the current setpoint correction. As a consequence, the current ageing correction at G2 is too conservative.

Hydro-Québec has therefore undertaken an update of the TTR-753 ROP setpoint analysis to include the new information on PT diametral creep rates; this update also includes the informations produced in response to CNSC questions and comments on the TTR-753 analysis [3,4,5]. This update simply repeats the TTR-753 analysis integrating the following changes:

- The measured diametral creep rates are used for the CCP calculations of the 62 pressure tubes for which measurements are available
- For channels not yet inspected, the RC-1980 model predictions are corrected to reproduce the average diametral creep rates based on the 81 inspections results
- The single phase reference hydraulic model is updated according to the TTR-753 methodology to reproduce, with the new diametral creep rates, the historical trends indicated by the monthly station channel heat balance data
- The following TTR-753 uncertainties are updated:
    - The standard deviation of the RC-1980 model prediction is determined based on the comparison of the predictions with the 81 inspection data; this standard deviation is applied to all channels in the core[1]
    - The integrated bundle two-phase pressure drop and CHF model bias and uncertainty are updated to account for the lower PT diametral creep rates

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[1] This is conservative for the 62 tubes for which the available measurements are used in the calculations; the standard deviation of the repeat measurements are in most cases much smaller than the standard deviation of all 81 inspections

    - The uncertainties in reactor header temperature, pressure and differential pressures are updated to account for the new information sent to the CNSC to obtain closure of station action item AI021009
    - The channel power uncertainty is updated to account for the 2004 TFD measurement [6]

- The ROP system modification during the outage of 2005: the adjustment for a uniform distribution of detector setpoint. The assignment of the HSP-3 in place of the HSP-2. The HSP-2 is now become *"Intermediate*", and HSP-3 "*abnormal*". The changes to the uniform setpoint have provided some ROP margin gain.
- The flux shapes are updated to include the new cases introduced after the issue of the TTR-753 for cobalt adjuster burnup and adjuster modeling.
- The revision of the flux shapes classification to reflect the changes of the operational rules in control room. In particular, the uses of the HSP-1 position for "*normal"* flux shapes and the HSP-3 "*abnorma*l" position for flux shapes excluded from HSP-1. The HSP-2 is temporary not allowed to be used.

The updated ROP setpoint calculation is documented in the reference [7] and the PT diametral deformation measurements analysis is documented in the reference [8]. This analysis brings no changes in the methodology used in the previous work, documented in TTR-753 "ROP Trip Setpoint Aging Trends for Gentilly-2". The same methodology is applied without exception.

2. Pressure tube diametral deformation

The TTR-753 analysis was based on PT diameter measurements with CIGAR in 1990, 1993 et 1997.

In 2002, an inspection was done with the MED tool. During this inspection PT diameter and thickness were measured for 45 tubes; the measurements include two repeat channels, L09 (in 1990 and 1997) and P16 (in 1990, 1993 and 1997), taken to establish consistency of the new MED tool with what had been measured previously with the CIGAR tool.

In 2003, an inspection was done with the CANDE tool . During this inspection PT diameter and thickness were measured for 15 tubes ; the measurements also included two repeat channels, taken to establish consistency with what had been measured previously with the MED and CIGAR tools.

The detailed measurement results presented in reference [8] are summarized in Figure 1 and Table 1. Figure 1 shows the channel locations and the number of measurements per channel; Table 1 provides for each inspection the ratio of the maximum measured diametral deformation to the maximum RC-1980 predicted diametral deformation.

The repeat measurements include:

- Channel P16 with 5 inspections : 3 with CIGAR, 1 with MED and 1 with CANDE.
- Channels L09, O08, O14, Q11 et S07 with 3 inspections: channels O08, O14, Q11 et S07 with 2 CIGAR and 1 CANDE measurements; channel L09 with 2 CIGAR and 1 MED measurements.

- Channels C16, F06, Q06, U09 et V11 with 2 inspections : channels C16 and Q06 with 1 CIGAR and 1 CANDE measurements; channel F06 with 1 MED and 1 CANDE measurements ; channels U09 and V11 have 2 CIGAR measurements.

For the CANDU-6 PT, the maximum deformation occurs at bundles 9 or 10, close to the preferred dryout location for slow LOR; therefore, the maximum diametral expansion is the most important parameter for determination of the impact of PT creep on CCPs. For ROP setpoint calculation, the key parameter for PT diametral creep is the bias and uncertainties in the prediction of the CCPs, which are directly related to the maximum diametral expansion.

The results in Table 1 show the values for the ratios of the measured channel maximum to the predicted channel maximum diameter. For the several channels gauged more than once (see figure 1), each measurement of these was given a weight of 1/n, where n is the number of gauging on that channel. The average bias of this ratio and the standard deviation are the relevant uncertainty for the ROP setpoint calculation. Figure 2 illustrates these results, comparing the measured maximum channel deformations to the RC-1980 predictions of maximum channel deformation; also shown is the RC-1980 average and 95% confidence levels.

Table 1 shows that RC-1980 correlation, based on the Wolsong, Point Lepreau and G-2 data, continues to overpredict the maximum channel creep rate seen at G2. For the entire current G-2 data base, the correlation yields an over prediction of 16.48% in the maximum crept channel diameter, with a standard deviation of 9.55%. Figure 2 shows that all but 3 of the 62 G2 measured pressure tubes have diametral creep rates below the RC-1980 average. Figure 3 shows the trend in RC-1980 overprediction converging to a bias of around 16%; Figure 4 shows the standard deviation reducing as data is added to the set and converging to a value around 10%.

For a given channel, Table 1 and Figure 2 show that variations seen in repeat measurements are much smaller than the channel to channel variation. This confirms that the channel to channel variations are real variations associated with channel specific micro-structure effects not represented in the models. Analysis of the G2 data shows that the channel-to-channel diametral expansion is normally distributed around a station specific average, with more than 95% of the measurements under the RC 1980 correlation.

3. Reference single phase hydraulic model

ROP setpoint are determined on the basis of CCPs. CCPs are obtained for a reference representation of the inlet to outlet header components including PT diametral deformation, known as the “Reference Model”. The effect of uncertainties and random process variations on CCPs are included in the setpoint calculations. Setpoint corrections are produced two to three times a week to account for drift or trends in the key process parameter and hydraulic data; corrections associated with hydraulic head variations are always a penalty. Trends are established on the basis of monthly monitoring of the difference between the flows predicted with the reference model for actual plant conditions and the single phase flow calculated from channel heat balance. Drifts are first investigated to identify if they can be the result of instrumentation drifts; in the cases where instrumentation drift is at cause, the situation is corrected by proceeding to instrument calibration; in cases where it is demonstrated that instrumentation is not at cause, the reference model is adjusted to reproduce the new best estimate of site data.

3.1 HTS Ageing

Since the introduction of the use of reference model to represent the impact on ROP of HTS ageing, three reference models have been used for setpoint calculation at G2:

- "TTR-610" reproducing the best estimate of site data at 3419 EFPD [10]
- "TTR-753" reproducing the best estimate of site data at 4968 EFPD [1]
- "G2-ATI-2004-68230-78" reproducing the best estimate of site data at 6000 EFPD [9]

Figure 5 reproduces the typical single-phase core pass flow evolution seen at G2 since around 3000 EFPD. The figure illustrates the reference hydraulic model prediction for plant conditions to the station channel heat balance calculation. As shown, "TTR-610" reproduces well the station data up to G2 primary side boiler cleaning in 1999. "TTR-753" was introduced in September 2000 when it was established that operation after primary boiler cleaning had resulted in a reduction of reactor header to header hydraulic resistance, associated with magnetite transport from the reactor feeders, end fittings and channels to the steam generators; "TTR-753" reproduces well station conditions since September 2000. During that period, two important drifts were observed with subsequent analysis and station measurements confirming that they were caused by drifts in boilers feed flow measurement. "G2-ATI-2004-68230-78" is a further adjustment to "TTR-753" to remove an unjustified ROP penalty on header-to-header differential pressure, without crediting the associated increase in authorized installed setpoints.

For the updated creep rates in reference [8], a revised reference model has to be established to reproduce the best estimate station data. The methodology; documented in TTR-753 is applied without exception, that is:

- The measured diametral creep rates are used for the 62 PT for which measurements are available
- The RC-1980 model predictions corrected by a factor of 0.84 are used for the channels that have not yet been inspected; the correction factor adjusts the RC-1980 prediction to reproduce the average diametral creep rates of all 81 inspections
- Component roughness and feeder pressure breakdown orifices discharge coefficients are adjusted to reproduce respectively station heat balance core pass flows and orifice and non-orifice region flows; adjustment to components are made according to the component adjustment parameters, component distribution and convergence criteria documented in TTR-753

Core specific magnitudes of the components roughness were assigned and the adjustment process reflects a roughness decrease trend with respect to TTR-753. This result is to be expected as the current reference model has a smaller creep rate than that in TTR-753. The component roughness of G2-RT-2005-68231-32 are closer to the design values indicating that the diametral strain rate may indeed have been overestimated in the previous "TTR-610" and "TTR-753".

Degradation of the ASME and CANDU feeder orifices is a well-known phenomena, confirmed by instrumented orifices channel flow measurement in all CANDU stations. Comparisons between NUCIRC hydraulic calculations and heat balance showed that the hydraulic resistance of channels with pressure breakdown orifices has decreased over time.

3.2 CCP Calculations

The CCPs for the first 50 limiting ROP flux shapes and for the nominal case were calculated. The CCP trends with aging are based on separate effect calculation for pressure tube diametral deformation with constant reactor header-to header condition. PHT boundary conditions variations are treated separately in the weekly calibration correction process. The CCP distributions are determined for all cases at 6211 EFPD, 6800 EFPD and 7300 EFPD (approximately the year 2009).

4. Uncertainties Update

The following TTR-753 uncertainties are affected by the new deformation and station data:

- The standard deviation of the RC-1980 model prediction is determined based on the comparison of the predictions with the 81 inspection data
- The integrated bundle two-phase pressure drop and CHF model bias and uncertainty are updated to account for the lower PT diametral creep rates
- The uncertainties in reactor header temperature, pressure and differential pressures are updated to account for the new information sent to the CNSC to obtain closure of station action item AI021009
- The channel power uncertainty in updated to account for the 2004 TFD measurement

The following summarizes the result on the ROVER-F uncertainties.

4.1 Channel Power at Calibration

Channel powers calculated by HQSIMEX are used to compute the CPPF in order to calibrate the ROP detectors. HQSIMEX uncertainties are evaluated periodically on the basis of traveling flux detector (TFD) measurements. The channel power uncertainty is updated to account for the 2004 TFD scan [6]. The value of 1.3% used in TTR-753 is increased to 1.38%. This value is independent of time.

4.2 HTS Boundary Conditions

The uncertainties in reactor header temperature, pressure and differential pressures are updated to account for the new information sent to the CNSC to obtain closure of station action item AI021009. The methodology and data used to derive the new values are documented in reference [11].

4.3 Diametral Creep

Both TTR-753 and this analysis determine the standard deviation of the RC-1980 model prediction based on the comparison of the predictions with inspection data. The data used in TTR-753 included 21 measurements for 12 channels from G2 and 28 measurements from Point Lepreau, which were added because of the small sample for G2. In the current analysis the G2 data includes 81 measurements for 62 channels. With the increased sample of G2 PT diameter measurements and the consistency of the G2 data, it is not necessary or justified to include the

Point Lepreau data. Independent review of the CANDU measurements concluded that PT diametral expansion at the different CANDU stations are constituted of different populations characterized by different micro-structures specific to the ingots from which PT were fabricated. This review also concluded that the data from Gentilly-2 are found to be sufficient for a probabilistic forecast of the peak diametral strain.

The result of using the complete G2 data sets reduces the standard deviation of the predictions from ±18.36% in TTR-753 to ±9.55% in the present analysis.

Although the relative uncertainty in diametral creep rate is constant, as illustrated in figure 4, the absolute diameter expansion, which is the key parameter for CHF, increases with operation and as a consequence, the uncertainty in absolute diametral expansion also increases as a function of time. As a consequence, the ROVER-F uncertainty is a function of EFPD. The uncertainty is therefore evaluated as a function of time, that is at 6211, 6800 and 7300 EFPD in this analysis.

TTR-753 shows that the CCP uncertainty associated to diametral expansion does not depend on flux shape. In this analysis, the uncertainties are determined on the basis of a limiting flux shape. This data is used to produce the following CCP decrease as a function of diametral expansion relative to 6211 EFPD:

$$\boxed{dCCP = - 0.005137\ d\varepsilon^2 - 0.003623\ d\varepsilon + 0.04000}$$

where dCCP : CCP fractionnal decrease and
$d\varepsilon$: the average diametral creep for the high power (CPPF) region in %.

Using this function, the ROVER-F uncertainties are obtained with the same methodology as that in TTR-753 producing the channel random and common random uncertainties.

4.4 NUCIRC Flow Uncertainty

The “NUCIRC Flow Uncertainty” represents the uncertainty associated with the single phase hydraulic data used in the CCP calculation. There are two components to the flow uncertainty: a common random component associated with the total bulk flow uncertainty and a channel random uncertainty associated with the channel flow uncertainty.

Common Random Component

The flow uncertainty is the integrated effects of the uncertainties on header-to-header components (feeders, fuel channel and end fitting) hydraulic data. The single-phase channel flows are obtained with the reference model, for which the single-phase hydraulic data is established on the basis of the channel heat balance flows. Therefore, the uncertainty of the heat balance data constitutes a common random uncertainty for the single-phase hydraulic data. These uncertainties are independent of the ageing parameters and therefore do not change with time.

The TTR-753 methodology is used to derive the components and total CCP common random uncertainty, using the new header parameters uncertainties described above (section 3.2) and the components fractional pressure drop and CCP sensitivities from case 39 (TTR-753 demonstrated that the uncertainty is not case dependant). The calculation using the new header parameters uncertainty produces a heat balance flow uncertainty of 1.951%, compared to

2.575% in TTR-753. The flow uncertainty is converted into the required CCP uncertainty according to TTR-753 using the components sensitivities, weighted by the components fractional pressure drop data: the sensitivities, fractional pressure drop. The total common random CCP uncertainty for the single phase hydraulic model is determined to be 1.342%, compared to 1.92% in TTR-753..

Channel Random component

The single-phase channel flows are obtained with the reference model, for which the single-phase hydraulic data is established on the basis of the channel heat balance flows. The reference model adjustments are defined on the basis core pass and core orifice and non-orifice region. Therefore, the hydraulic parameters do not vary from channel to channel in a core pass or core region and actual channel-to-channel variations and channel heat balance uncertainties are not represented in the hydraulic model. These constitute a channel random uncertainty that needs to be included in the CCP uncertainties for the setpoint calculation.

The channel random variations and channel flow uncertainties are included in the channel heat balance data; as a consequence the standard deviation in the channel flow reference model predictions to the best-estimate station data provides an estimate of the channel random flow uncertainty. The standard deviation is 3.815% for the orifice region and 3.534% for the non-orifice region. Since the ROVER-F version in the analysis uses a single uncertainty value for all channels, the higher value 3.815% is used to derive the CCP uncertainty. The CCP uncertainty is obtained with the header-to-header flow sensitivity (0.688%CCP/%Flow), resulting in a channel random component of 2.625%, compared with 1.74% in the previous analysis.

4.5 Integrated Two-Phase Flow and CHF

The “Integrated Two-Phase Flow and CHF” represents the uncertainty associated with the two phase hydraulic and CHF models used in the CCP calculation. This component is established on the basis of comparisons to the full-scale water tests data. Since the channel specific two-phase flow conditions at CCP are calculated for each channel, the uncertainties apply equally to all channels, resulting in *a common random component*.

The NUCIRC validation documented in COG-00-005 is applied to NUCIRC-MOD2.000. As a consequence, the applicable uncertainties are simply calculated for the new diametral creep rates using the same methodology as TTR-753. Since the uncertainties are function of creep these uncertainties vary with time.

5. Setpoint Calculations

Setpoints are determined with ROVER-F calculation using the new set of CCPs and uncertainties described above.

In the current analysis , the ROP trip setpoints were arranged into one setpoint plateau. Calculation of the ROP trip setpoints use an uniform distribution for the base ROP trip setpoints. Revision of the limiting ROP flux shapes were necessary because of the addition of new ROP cases to take into account the effect of the cobalt adjuster and to include the various physics models of cobalt adjusters in the core. The setpoints are calculated for the normal ROP handswitch position (HSP-1) and for the abnormal handswitch position (HSP-3) in order to confirm that the reduction of ROP setpoints installed during the 2005 shut-down for this position remains valid. The setpoints for the intermediate hand switch position (HSP-2) were not considered since its use is not authorized.

ROVER-F calculations are performed at 6211, 6800 and 7300 EFPD. Trends of the base HSP-1 flux shapes ROP trip setpoints are explicitly fit by the quadratic curve:

$$\textbf{\textit{ROP Trip Setpoint (\%)}} = -2.0405\times10^{-7}\,EFPD^{2} + 9.5706\times10^{-4}\,EFPD + 114.65$$

Ratios of abnormal/normal ROP trip setpoints for the 3 EFPD confirms that the ROP trip setpoints installed during 2005 plant outage for the abnormal (HSP-3) hand-switch position remain valid and adequate.

6. Conclusion

Figure 6 compares the ROP setpoints obtained on the basis of the updated analysis with the TTR-753 analysis. Current setpoints are higher and decrease slower with time. The large gain in ROP margin results from the introduction of the new station data on pressure tube diameter expansion. Analysis and independent review of the G2 data concludes that the diametral expansion rate associated with creep is lower at G2 with more than 95% of the measurements below the values predicted by the CANDU-6 RC-1980 model and that the sample size is found to be sufficient for a probabilistic forecast of the peak diametral strain. The uncertainty in the RC-1980 prediction of the measurement set is also smaller than that used in TTR-753.

The reduced diametral creep rate results in higher setpoints and the reduced uncertainty in diametral creep predictions produces the lower decrease in setpoints with time.

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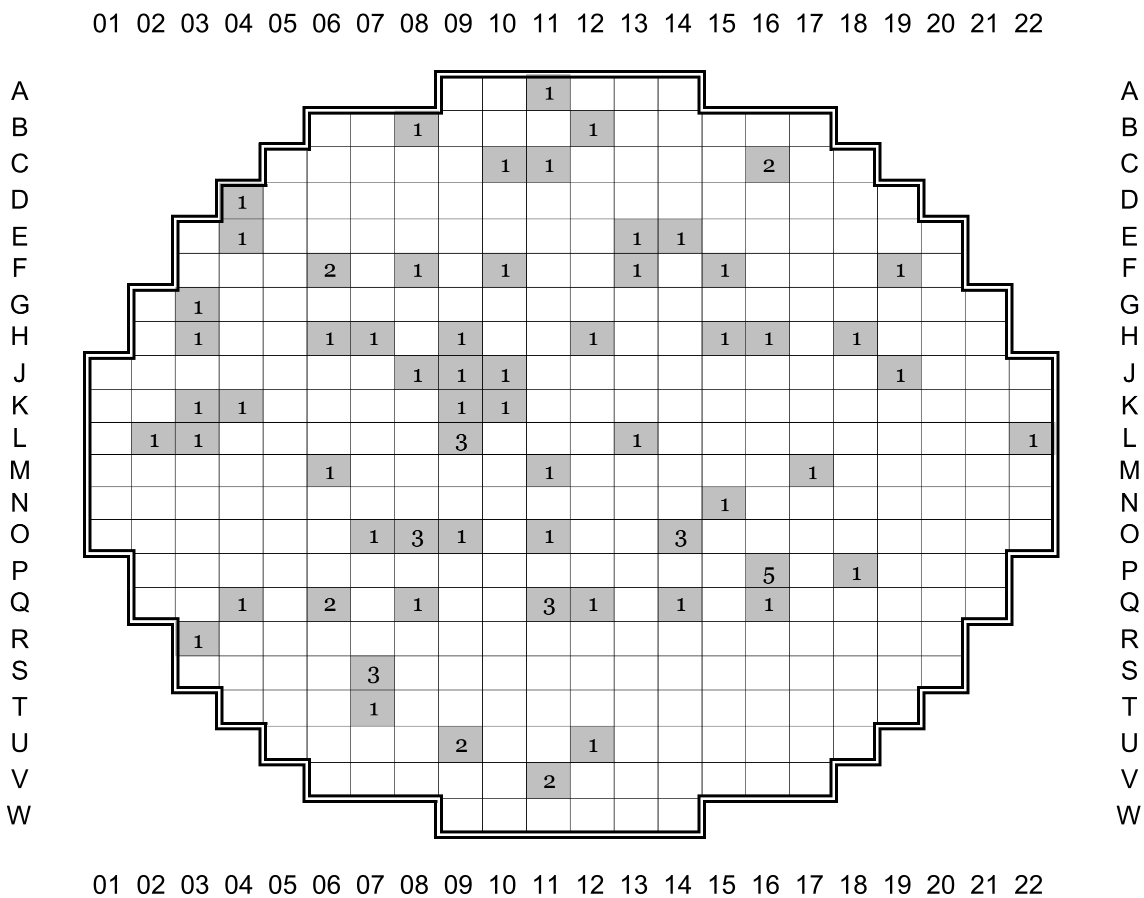

Figure 1
Channel map for the sites and number of PT diameter gauging at each site

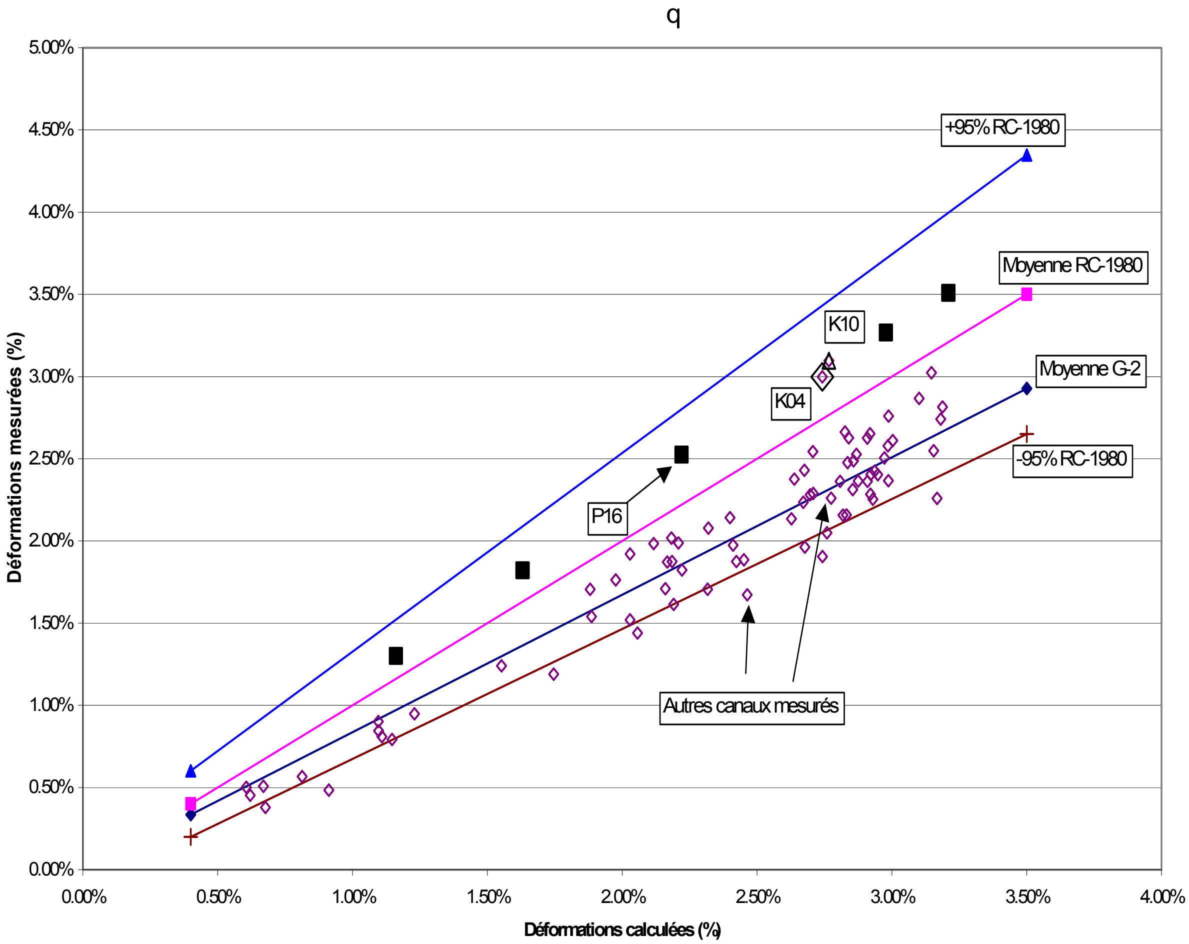

Figure 2
Comparison of measured and RC-1980 prediction of maximum channel diametral deformations at G2

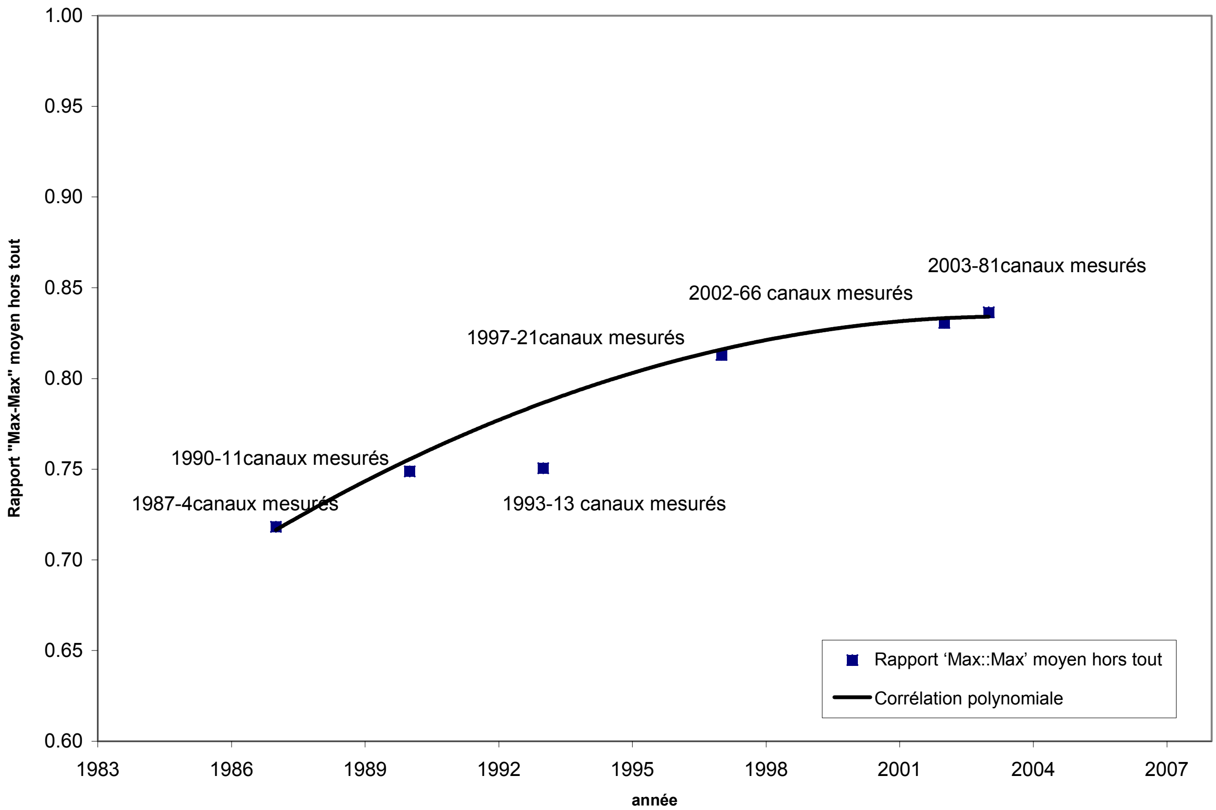

Figure 3
Average of ratio between the maximum measured deformations and the maximum deformations predicted by RC-1980 at each year of inspection

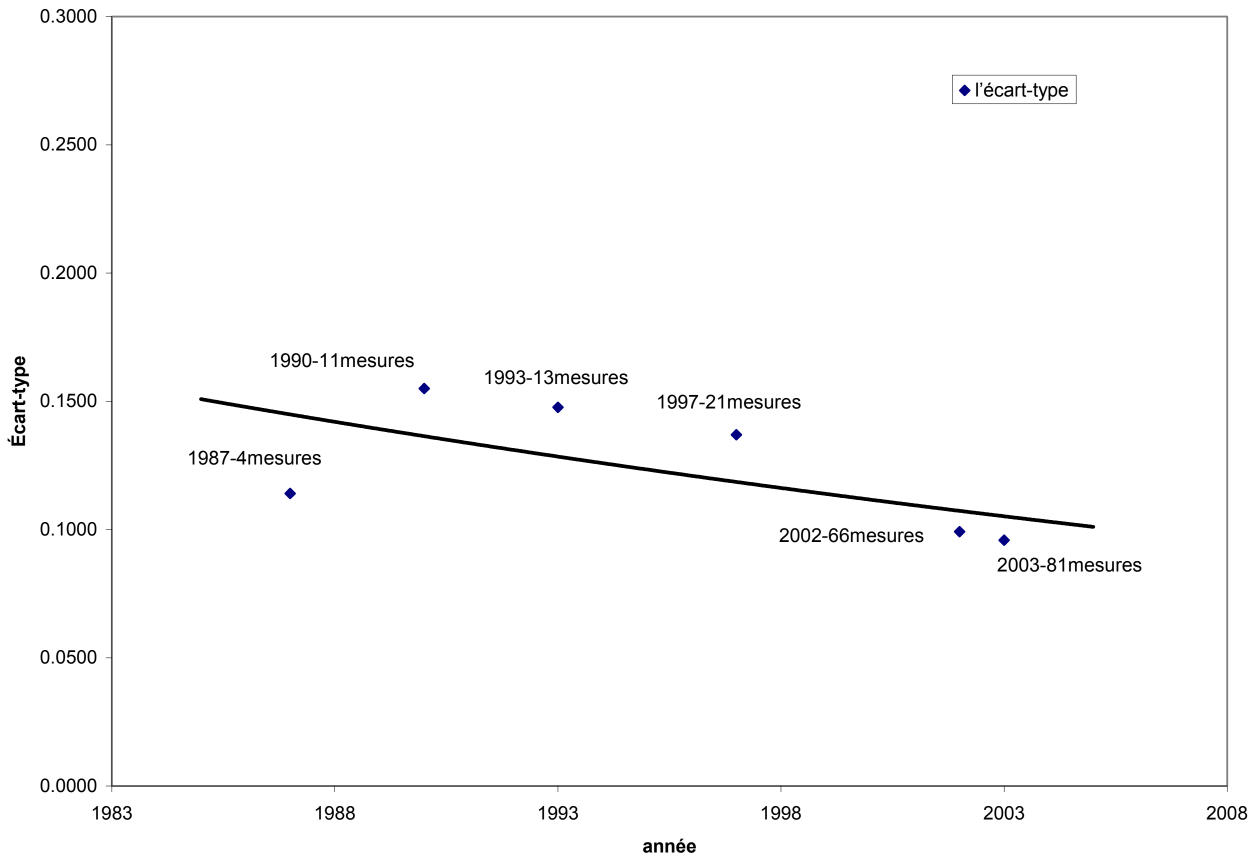

Figure 4
The standard deviation of the ratio between the maximum measured deformations and the maximum deformations predicted by RC-1980 at each year of inspection.

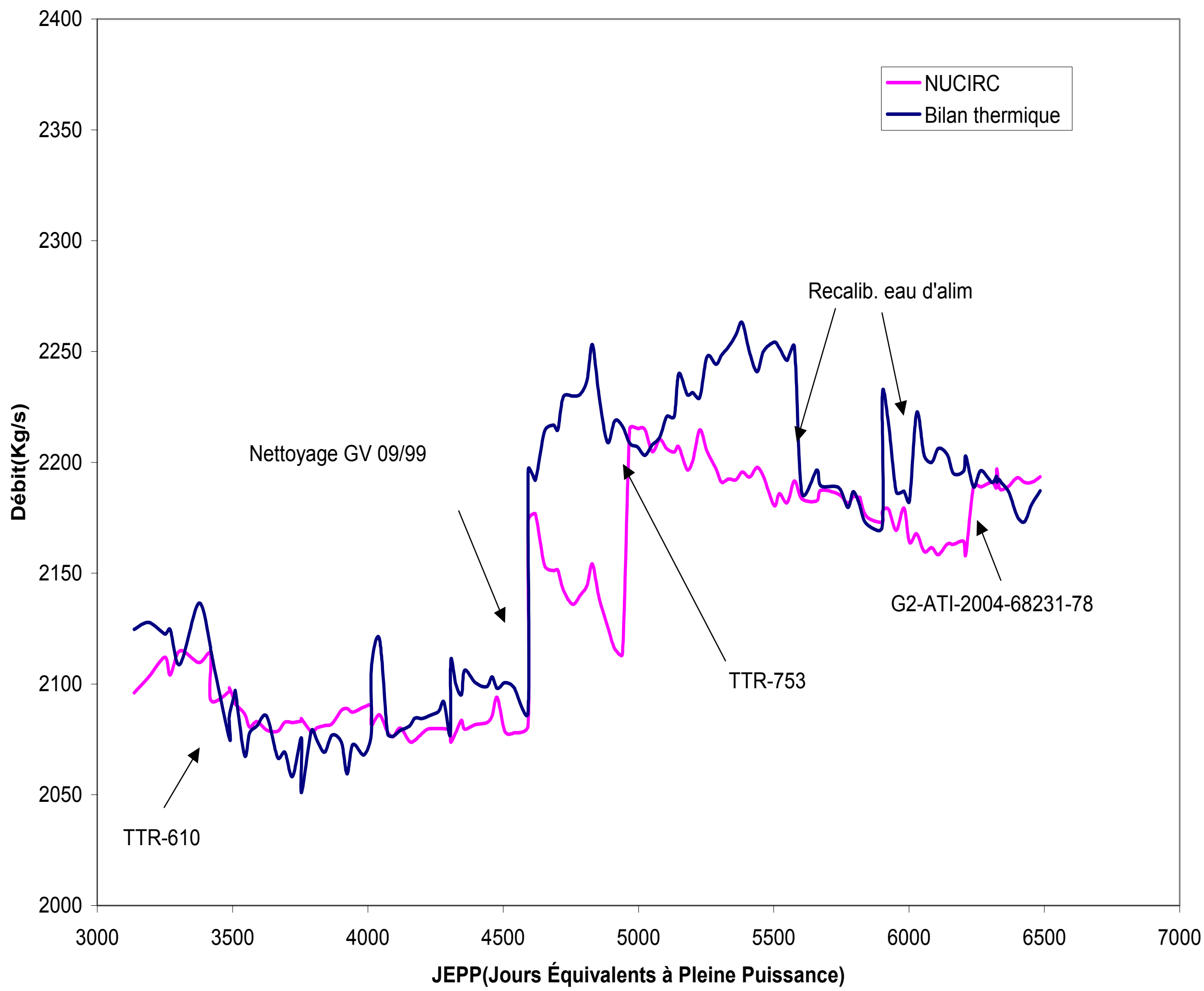

Figure 5
Single Phase Core flow Evolution – Core Pass from HD4 to HD1

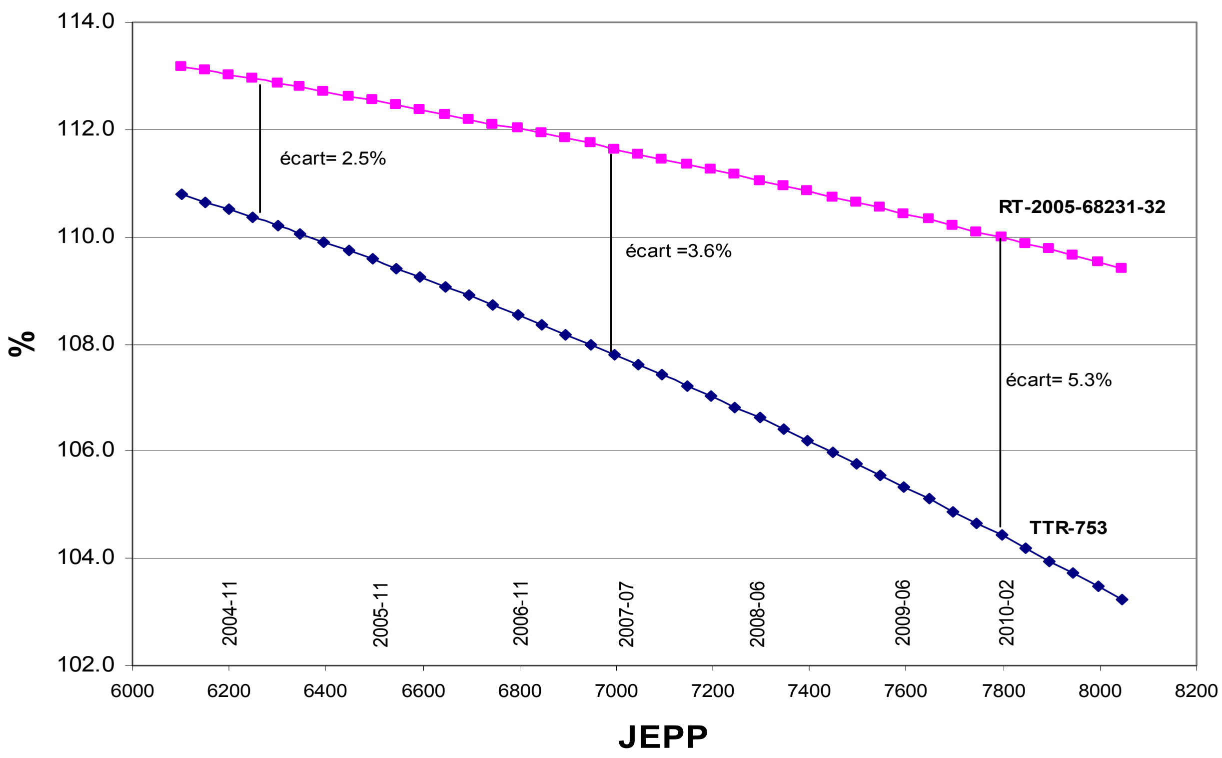

Figure 6

Comparison of TTR-753 and RT-2005-68231-32 Effective ROPT Setpoints

Table 1
Ratio of the measured maximum channel diameter deformation to the RC-1980 predicted maximum channel diameter deformation ($\varepsilon_{MEASURED}/\varepsilon_{CALCULATED}$ 'Max::Max')

	Inspections						
Channel	**1987**	**1990**	**1993**	**1997**	**2002**	**2003**	**average**
A11					0.8166		**0.8166**
B08					0.7001		**0.7001**
B12					0.7915		**0.7915**
C10					0.7692		**0.7692**
C11					0.6789		**0.6789**
C16			0.7717			0.7734	**0.7725**
D04					0.9068		**0.9068**
E04					0.8634		**0.8634**
E13					0.8451		**0.8451**
E14					0.9394		**0.9394**
F06					0.9006	0.9250	**0.9128**
F08					0.8415		**0.8415**
F10						0.8231	**0.8231**
F13						0.8230	**0.8230**
F15						0.8641	**0.8641**
F19					0.8204		**0.8204**
G03					0.9246		**0.9246**
H03					0.7361		**0.7361**
H06					0.7426		**0.7426**
H07					0.8810		**0.8810**
H09					0.8100		**0.8100**
H12						0.9245	**0.9245**
H15					0.6945		**0.6945**
H16					0.8122		**0.8122**
H18					0.8454		**0.8454**
J08					0.7654		**0.7654**
J09					0.9423		**0.9423**
J10					0.8258		**0.8258**
J19					0.8366		**0.8366**
K03					0.8122		**0.8122**
K04					1.0934		**1.0934**
K09					0.7625		**0.7625**
K10					1.1196		**1.1196**
L02					0.8953		**0.8953**
L03					0.9078		**0.9078**
L09		0.7297		0.9374	0.8733		**0.8468**
L13		0.8235					**0.8235**

	Inspections						
Channel	**1987**	**1990**	**1993**	**1997**	**2002**	**2003**	**average**
L22					0.7487		**0.7487**
M06					0.7690		**0.7690**
M11	0.7296						**0.7296**
M17					0.8227		**0.8227**
N15					0.9088		**0.9088**
O07					0.9234		**0.9234**
O08	0.5587			0.8996		0.8833	**0.7806**
O09					0.7821		**0.7821**
O11					0.8429		**0.8429**
O14	0.757			0.8580		0.8081	**0.8078**
P16		1.1200	1.1169	1.1375	1.0974	1.0935	**1.1130**
P18					0.8148		**0.8148**
Q04						0.7327	**0.7327**
Q06		0.7706				0.8692	**0.8199**
Q08						0.9608	**0.9608**
Q11		0.6911		0.7363		0.7132	**0.7135**
Q12					0.7922		**0.7922**
Q14					0.8153		**0.8153**
Q16						0.8619	**0.8619**
R03					0.9468		**0.9468**
S07	0.8274			0.8921		0.8699	**0.8631**
T07					0.8922		**0.8922**
U09		0.5316		0.6812			**0.6064**
U12					0.8186		**0.8186**
V11		0.6959		0.7988			**0.7473**
Ratio ‘Max::Max’ average:							**0.8352**
Standard Deviation :							**0.0955**