ASSESSMENT OF GAS GAP EVALUATION FOR THE IGNALINA NPP RBMK-1500

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Outline

- Gas gap closure issue for RBMK-1500
- Measurement data of fuel channel and graphite moderated brick diameters and statistical evaluation
- The models of pressure tube and graphite bore diameters
- Gas gap closure probabilistic estimation mathematical models
- Results and their analysis
- Conclusions

Gas gap closure issue for RBMK-1500

- The RBMK reactor is designed to use a graphite moderator in the form of graphite bricks which surround Zirconium-Niobium channels (or “pressure tubes”) containing the nuclear fuel and coolant.

- The pressure tube is initially positioned in place by a series of graphite rings that are alternately in contact with the inner bore hole of the graphite bricks and the outer perimeter of the pressure tubes.

- The initial design was to provide a nominal 2.5-3 mm gap between the pressure tubes and the rings, filled with 10% helium and 90 % nitrogen gas mixture.

- The gas gap is needed for:
    - Cooling of graphite bricks;
    - Changes of the pressure tubes due thermal influence;
    - Detection of rupture of the pressure tube.

Gas gap closure issue for RBMK-1500 (cont.)

- It is well known that the initial gaps will contract as a result of radiation and temperature induced shrinkage of the graphite and outward creep of the pressure tubes.

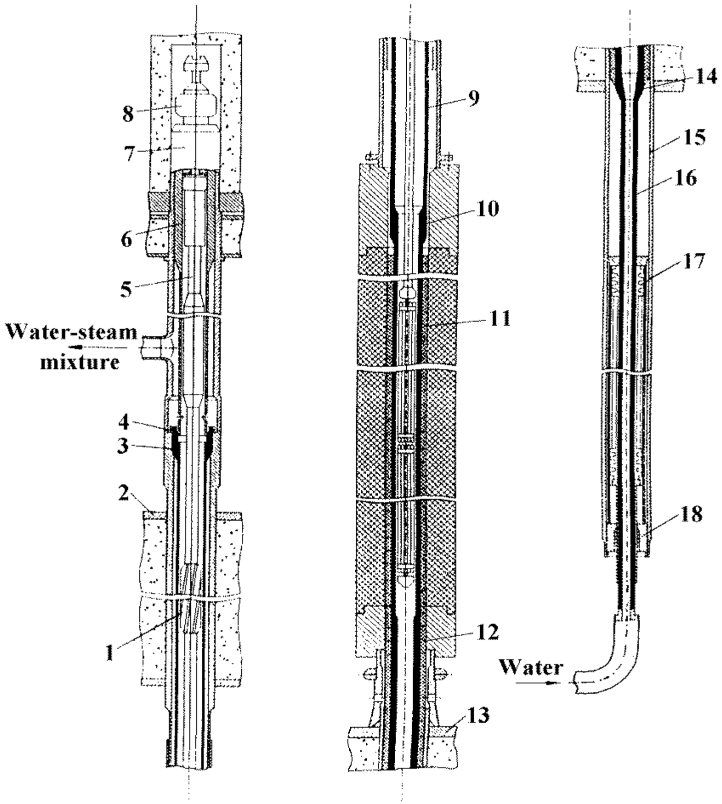
- Recently completed Safety Analysis Report (SAR, 1996) and Review of Safety Report (RSR, 1997) of the Ignalina NPP concluded that closure of the gas gap between the fuel channels and graphite bricks is one of the most important reactor operation lifetime criteria.

- The thermal hydraulic calculations showed that the temperature of pressure tube would be able to increase about 20-25 °C due to closure of gas gap.

- According to new Technical Specification: “Plant must show that with confidence 0.95 there will be no channels with zero gap until next outage including data collected during current planned preventive maintenance".

Individual Fuel Channel

- Top, centre and bottom segments of a typical reactor fuel channel are shown in the picture;
- **Center segment (9) is 7 meters high and made from Zirconium and 2.5% Niobium alloy, which assures relatively low thermal neutron absorption cross-section;**
- Initially 2% enriched uranium fuel in the form of uranium dioxide was used, nowadays converted to 2.4%.



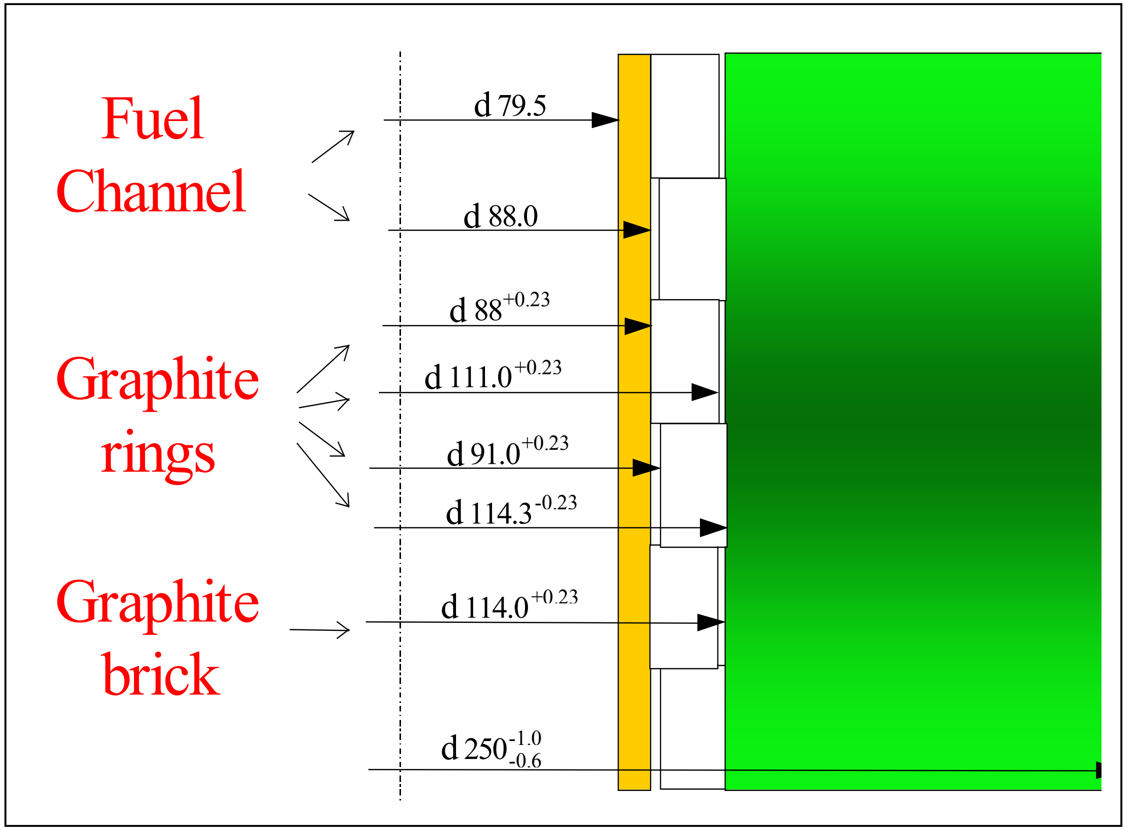
Fuel channel assembly. 1 - steel biological shield plug, 2,10 - top and bottom metal structures, respectively, 3 - top part of the fuel channel, 4 - welding-support ledge, 5 - fuel assembly support bracket, 6 - encasement cylinder, 7 – seal plug, 8 - graphite cylinder, 9 - central part of the channel, 11 - bottom part of the channel, 12 - thermal expansion bellows compensator, 13 - stuffing box, 14 - lower FC housing, 15 - FC lower part, 16 - compensating bellow, 18 – water, 19 - steam-water mixture.

Fuel Channel – Graphite Gas Gap

- Fuel channel is located in the graphite column central hole by a system of graphite split rings.

- Interaction of fast neutrons lead to dimensional changes in graphite and fuel channel materials;

- This effect produces a gradual shrinkage of the graphite blocks and expansion of the fuel channel outside diameter.



Measurement data till year 2001

The amount of measurements:

- 1244 pressure tube diameters;
- 65 repeated measurements of pressure tubes;
- 233 graphite bore diameters;

The measurements of graphite diameters were performed for each graphite brick (14 for each channel).

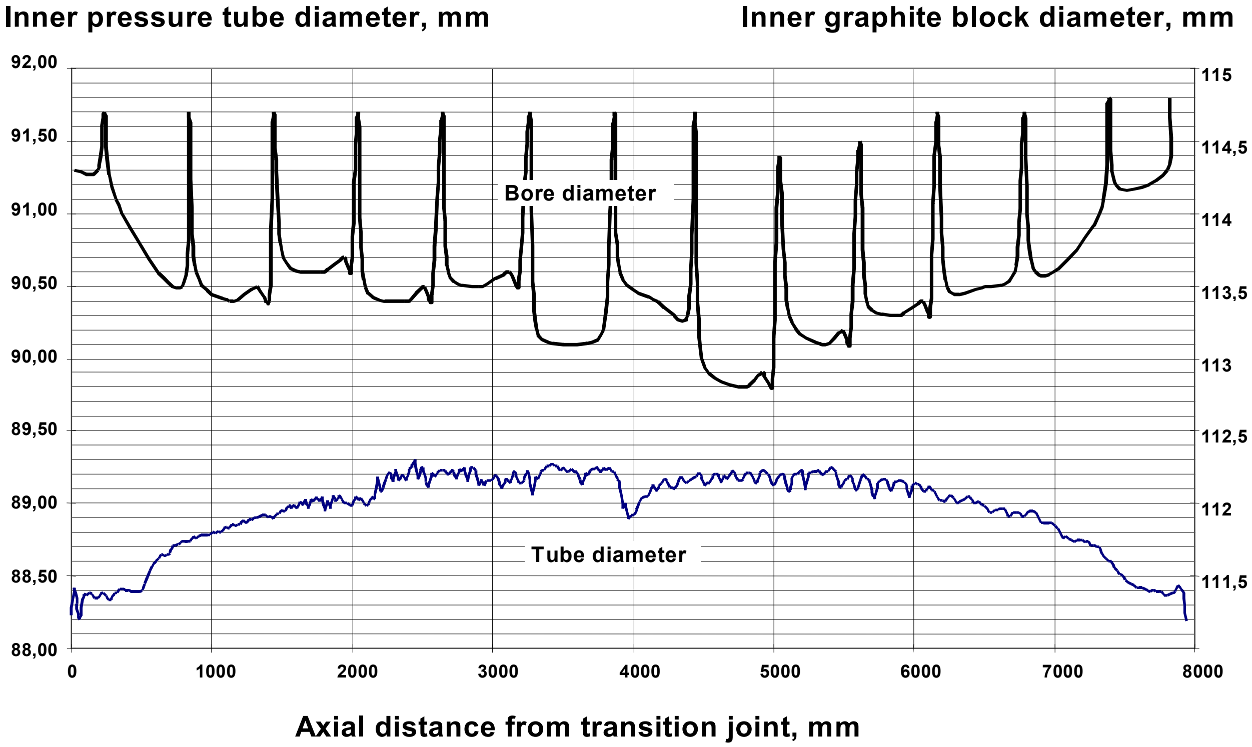
The measurement of diameters is performed using the equipment, which error of measurement is ±0.5mm.

The designed pressure tube and graphite brick can have diameter deviation correspondingly equal 0.8mm and 0.23 mm.

These deviations are the main uncertainty sources.

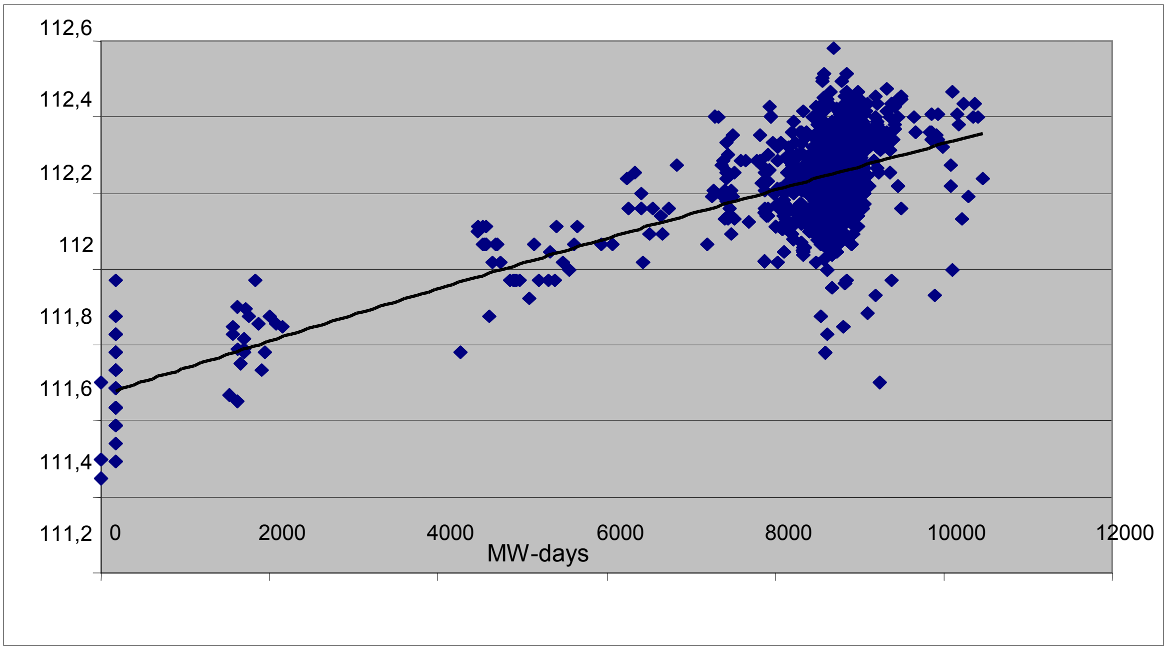
Accumulated burn-up in each channel is calculated for each year.

Statistical data evaluation



Measurements of inner pressure tube diameter and graphite bore diameter in 12-10 channel, recorded in 1998.

The mathematical model of pressure tube diameter



Linear trend of 1200 pressure tubes outer diameters

The linear trend equation for pressure tube is

$$y = 0{,}000057x + 111{,}61955$$

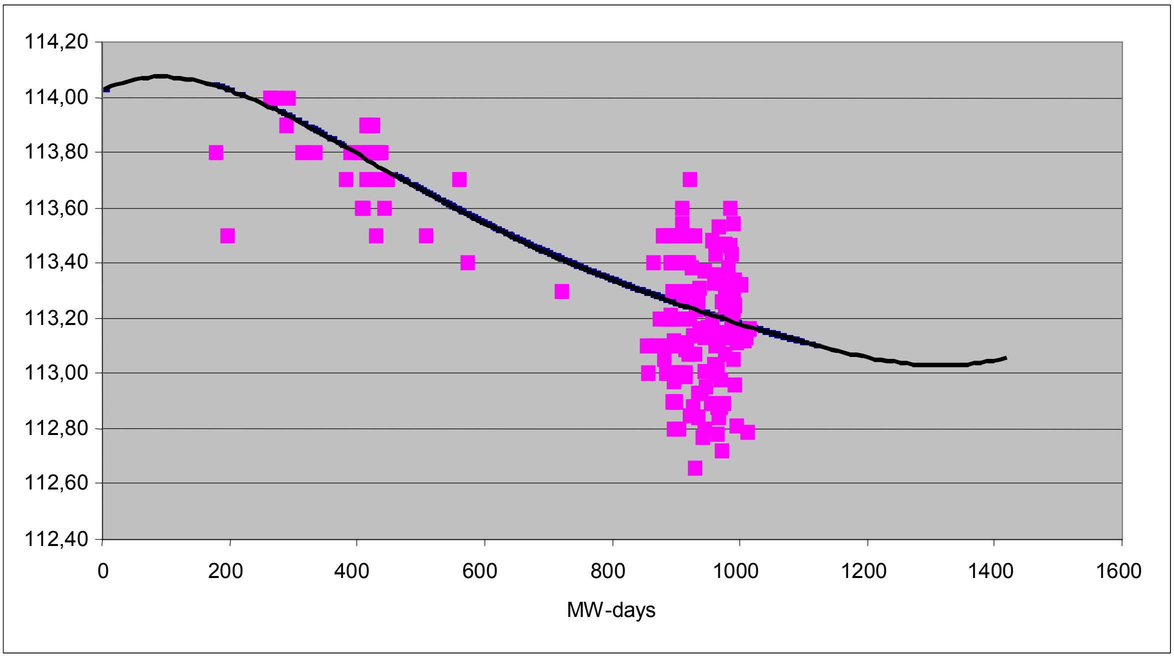
The diameter of each pressure tube is normally distributed random value with mean y and standard deviation 0.16 mm.

The performed analysis showed that parameters of this model remain stable during the operation time.

The mathematical model of graphite brick diameter

- The model of diameter of graphite brick is non-linear.

- Theoretically it is known that graphite induced by radiation and temperature in initial lifetime stages expanding but later shrinking.



Graphite brick' behavior modeling using code ABAQUS (8th graphite brick)

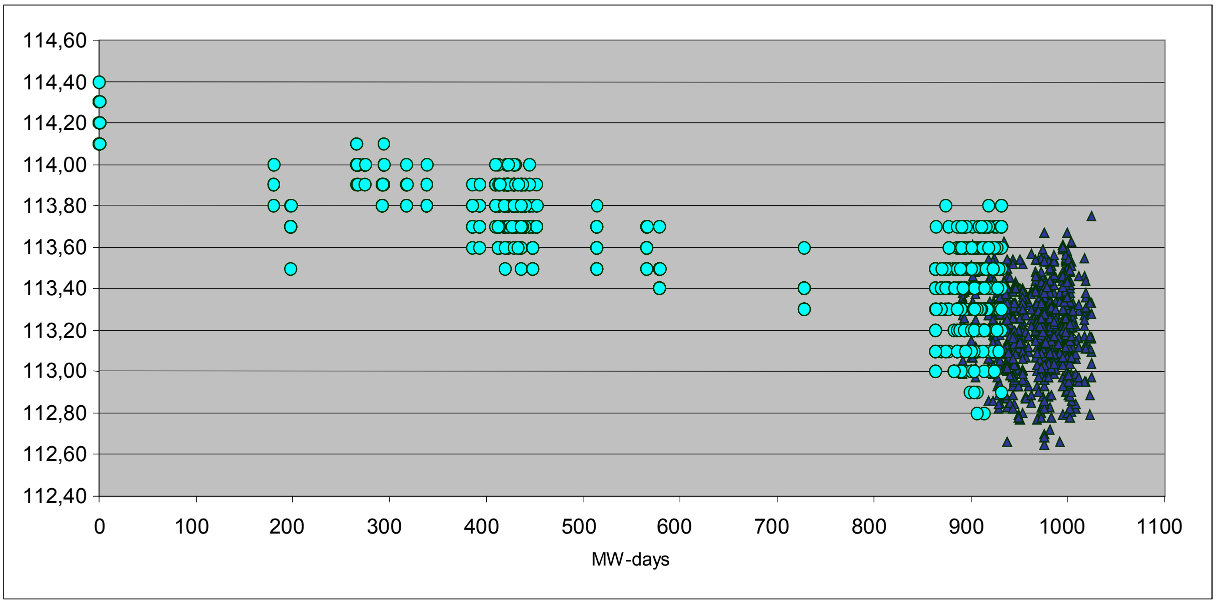
- The non-linear graphite trends were calculated for each graphite brick.

The mathematical model of graphite brick diameter (cont.)

- The standard deviations of graphite brick diameters are presented in the following table.

Block No.	Standard deviation	Up to 2000-year	2000-year
4	0,173	0,158	0,186
5	0,179	0,191	0,169
6	0,178	0,148	0,202
7	0,162	0,152	0,171
8	0,203	0,185	0,218
9	0,186	0,177	0,194
10	0,170	0,172	0,169
11	0,195	0,165	0,220

- The diameter of each bore of graphite brick is assumed as normally distributed random value.



Graphite up to 2000-year measurements comparison with 2000-year measurements (dark points)

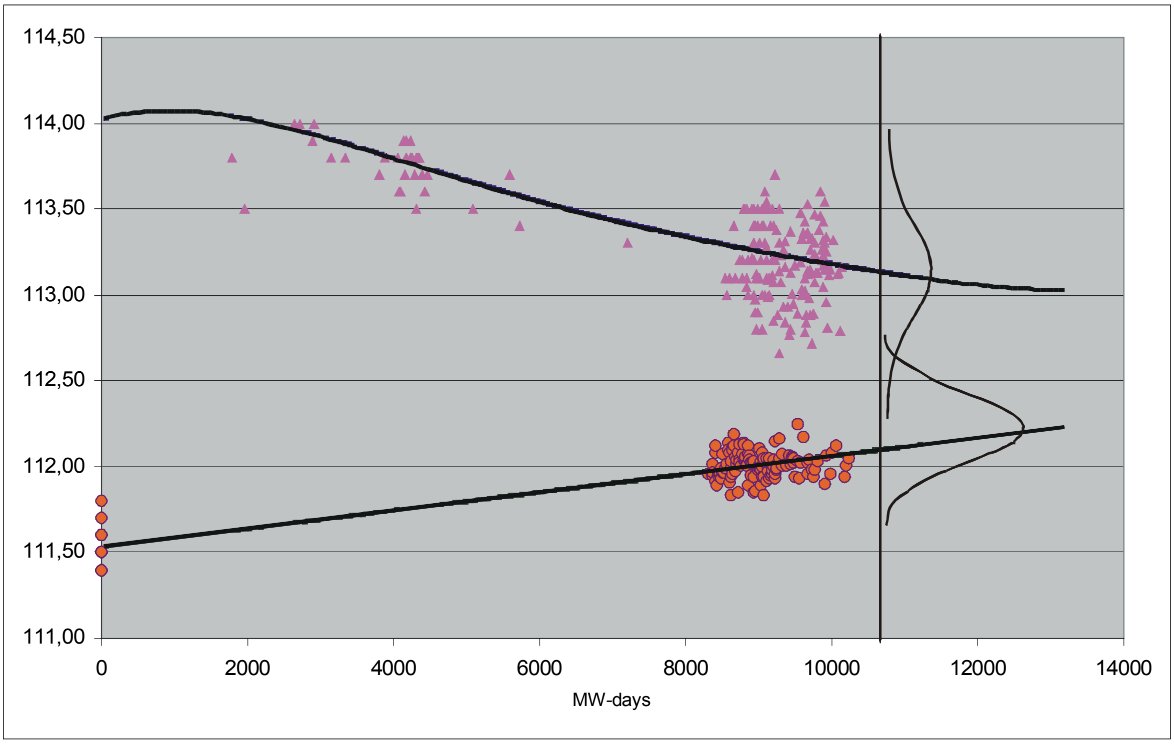
Mathematical models for gas gap closure probabilistic estimation

Gas gap closure probability is calculated using formula:

$$\mathrm{P}(Gr \le PT) = \int_{-\infty}^{\infty} F_{Gr}(x)\, p_{PT}(x)\, dx, \qquad \text{where} \qquad F_{Gr}(x) = \int_{-\infty}^{x} p_{Gr}(x)\, dx$$

$$p_{Gr}(x) = \frac{1}{\sqrt{2\pi}\sigma_{Gr}} e^{-\frac{(x-M_{Gr})^2}{2\sigma_{Gr}^2}}$$

$$p_{PT}(x) = \frac{1}{\sqrt{2\pi}\sigma_{PT}} e^{-\frac{(x-M_{PT})^2}{2\sigma_{PT}^2}}$$



Probability estimation of gas gap closure by normal distributions of graphite and pressure tubes up to year 2003

Mathematical models for gas gap closure probabilistic estimation

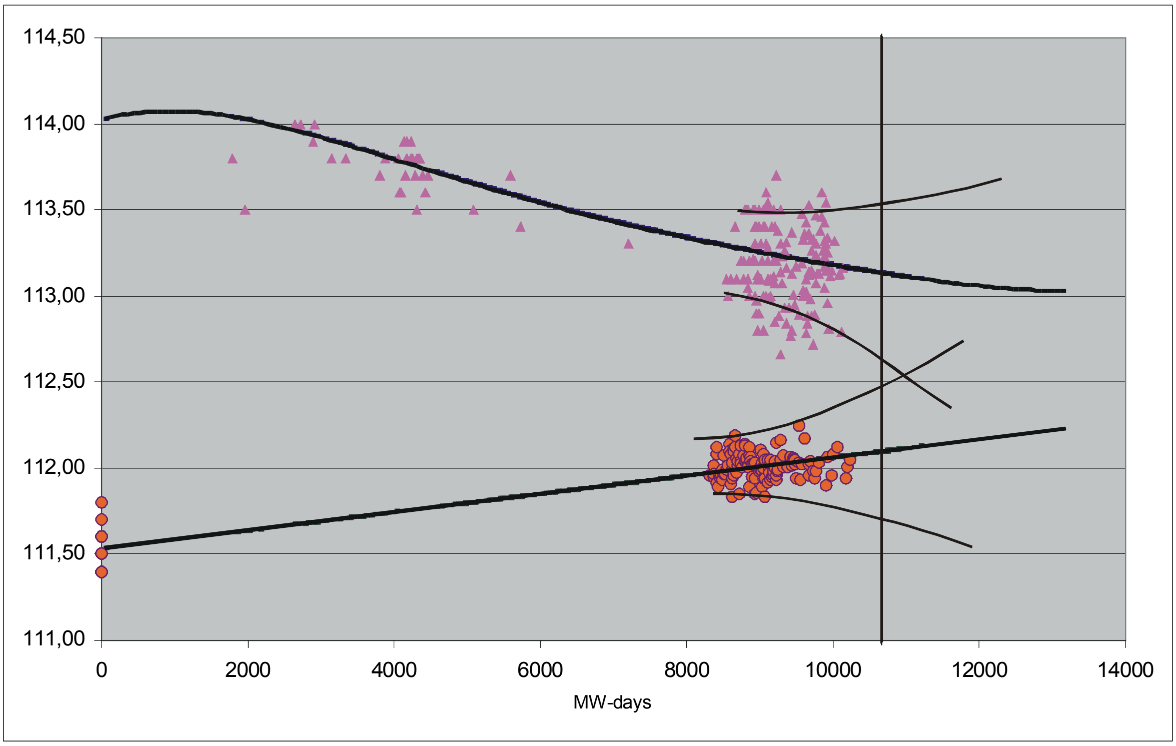
The probability of gas gap closure on 2003 year was estimated from confidence intervals. The estimate was received from the following equation:

$$t_{n_{Gr}}\left(\frac{\alpha}{2}\right)\sigma_{Gr}\sqrt{1+\frac{1}{n_{Gr}}+\frac{(E_0-\bar{E}_{Gr})^2}{\sum(E_{Gr_i}-\bar{E}_{Gr})^2}}+t_{n_{PT}}\left(\frac{\alpha}{2}\right)\sigma_{PT}\sqrt{1+\frac{1}{n_{PT}}+\frac{(E_0-\bar{E}_{PT})^2}{\sum(E_{PT_i}-\bar{E}_{PT})^2}}=M_{Gr}-M_{PT}$$

M_{Gr}, M_{PT} – graphite and pressure tube mean values respectively.

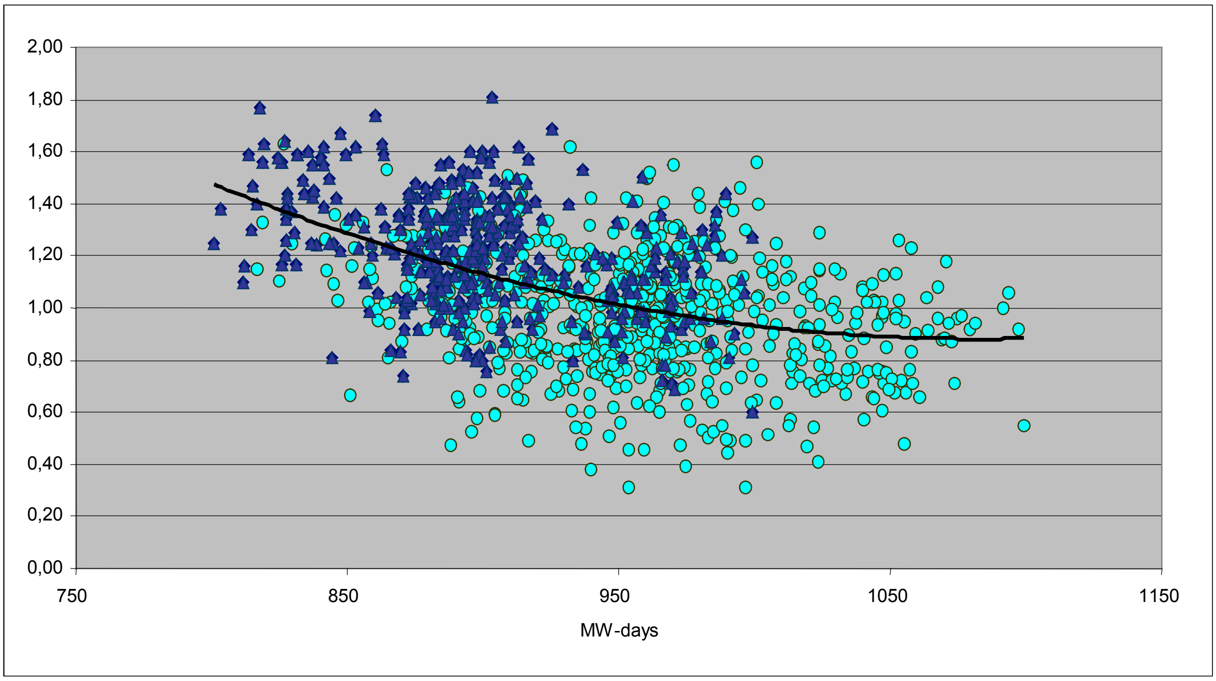
Probability of gas gap closure in one channel:

$$P_i=\left(\frac{\alpha}{2}\right)^2$$, where α - equation solution



Probability estimation of gas gap closure by confidence intervals of graphite bricks and pressure tubes diameters mean values up to year 2003

Results and their analysis



Measurements of gas gap in graphite bricks
(1998- dark points, 2000- light points)

- The measurements can be approximated using parabolic curve.

Gas gap existence in every channel is calculated using the following formula:

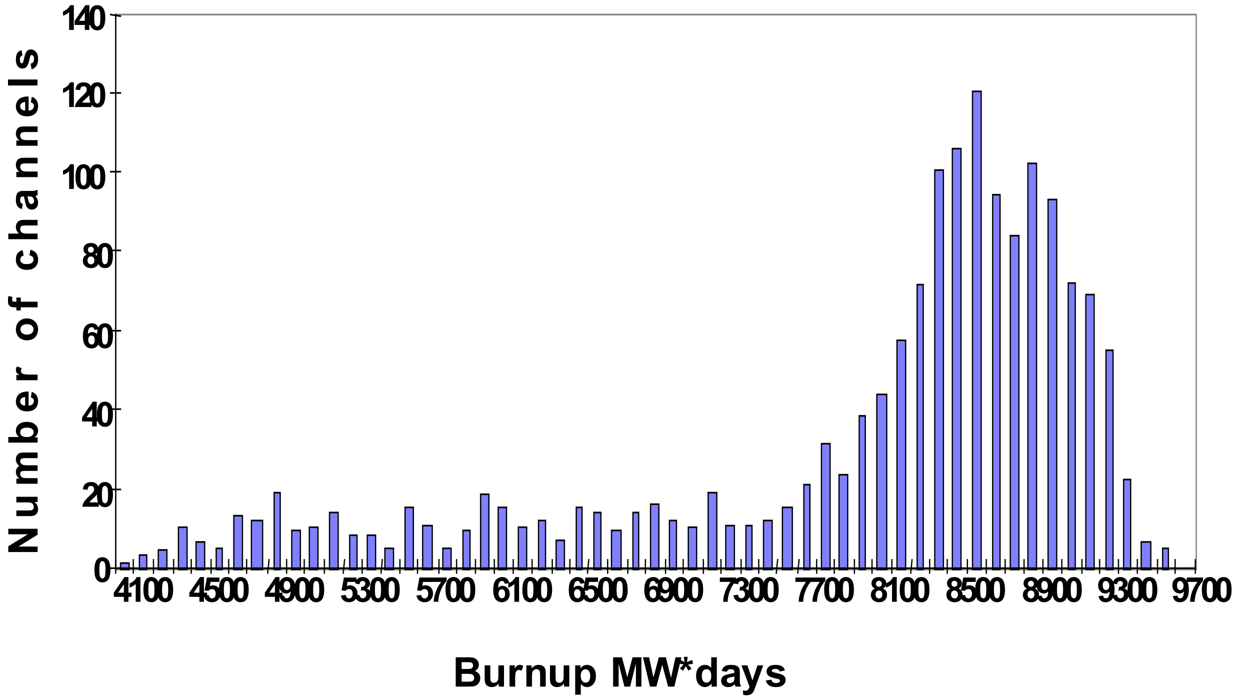
$$P = 1 - \prod_{i} (1 - P_i)$$

Results and their analysis (cont.)

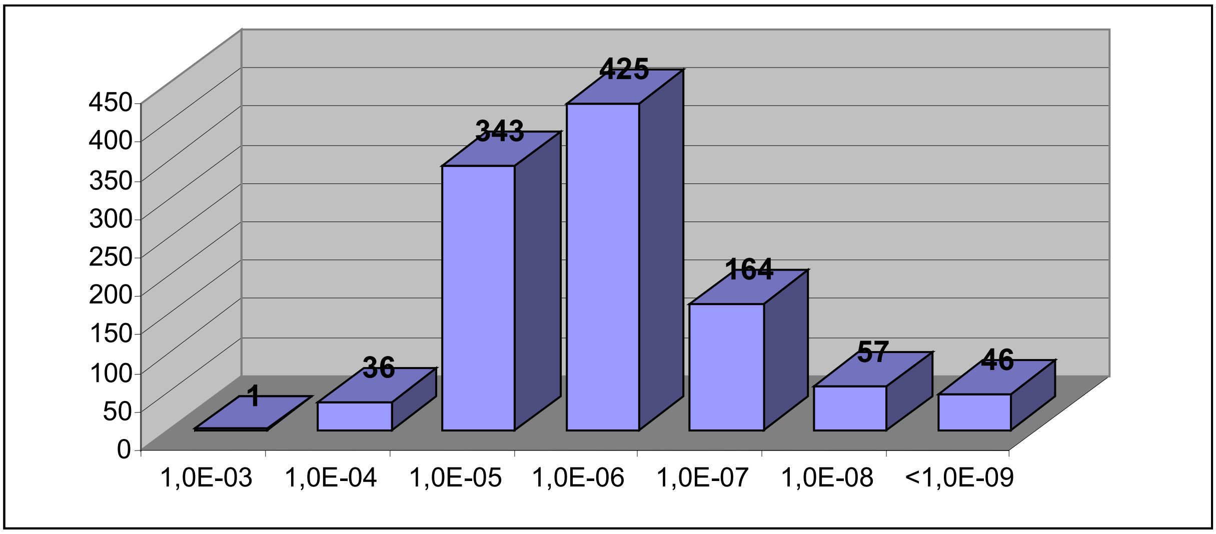
Probabilities of gas gap closure till 2003
in several channels

Channel	MW*days	Probability
40-20	10766	2,398E-03
41-36	10104	5,445E-04
43-28	9950	4,774E-04
20-39	10246	4,455E-04
09-24	10108	3,152E-04
13-28	10020	3,107E-04
27-06	10129	2,664E-04
29-19	10249	2,578E-04
11-38	10193	2,431E-04
08-26	10032	9,266E-05
…	…	…
42-29	10083	7,955E-06
33-17	9642	7,945E-06
34-28	9897	7,938E-06
24-24	9351	1,126E-07
26-36	9079	1,067E-07
46-28	8645	1,049E-07
34-24	9996	1,031E-07
10-40	9484	1,011E-07
33-34	8911	9,330E-08
37-19	9023	9,071E-08
…	…	…
48-22	7162	1,302E-09
20-11	10296	1,075E-09
37-32	9750	1,062E-09
42-37	8629	5,339E-10
24-20	9558	2,027E-10

Results and their analysis (cont.)



Distribution of the channel burn-up (1998)



Channel distribution by probabilities

Results and their analysis (cont.)

Analysis of probability sensitivity to graphite bricks and pressure tubes variance

$\sigma_{Gr}+10\%$	$\sigma_{Gr}+5\%$	σ_{PT}, σ_{Gr}	$\sigma_{Gr}-5\%$	$\sigma_{Gr}-10\%$
0.95	0.97		0.99	0.998
		0,98		
$\sigma_{PT}+50\%$	$\sigma_{PT}+20\%$		$\sigma_{PT}-20\%$	$\sigma_{PT}-50\%$
0.96	0.97		0.98	0.99

Probability that there will be no channels with zero gaps in reactor unit 1 until 2003 is not less than 0.98

The gas gap closure probability is very sensitive to the variance of the bore of graphite bricks.

Conclusions

- The non-linear behavior of graphite bricks showed that decrease of gas gap is almost stabilized.

- The results of the gas gap closure probabilistic modeling indicate that the gap non-closure probability for period until 2003 year is less then 0.98.

  The recently approved success criterion for gas gap non-closure probability is 0.95.

- The gas gap closure probability is very sensitive to the variance of the bore of graphite bricks.

- The probabilistic analysis of gas gap closure should be done after new measurements in order to confirm requirements stated in Technical Specifications.