WANO

Moscow Centre

Annual Report

WANO Performance Indicators

4th quarter 2017

MOSCOW

March 2018

Table of Contents

ACRONYMS

ALARA – concept of exposure levels optimization «As Low As Reasonably Achievable»
DES – Data Entry System
PWR, VVER – Pressurized Water Reactor
SCRAM – Safety Control Rod Actuation Mechanism
AC – Atlanta Center
NPP – Nuclear Power Plant
FBR – Fast Breader Reactor
WANO – World Assosiation of Nuclear Operators
WANO MC – Moscow Center of WANO
CP – Chemistry Performance
DG – Diesel - Generator
IAEA – International Atomic Energy Agency
MC – Moscow Center
SM – Support Mission
OA – Occupational Accident
OE – Operating Experience
DIR – Design Informed Review
PR – Peer Review
PI – Performance Indicators
LWCGR –light water cooled graphite moderated reactor
PC – Paris Center
RF – Reactor Facility
RC – Regional Center
HPSI – High Pressure Safety Injection System
SS – Safety System
TS&E – Technical Support and Exchange
TC – Tokio Center
EGP – graphite-moderated boiling-water reactor for combined heat and power

Introduction

The WANO performance indicators have been adopted to provide a quantitative indication of plant performance in the areas of nuclear plant safety and reliability and personnel safety. These indicators are intended principally for use by nuclear operating organisations to monitor performance and progress, to set challenging goals for improvement, to gain additional perspective on performance relative to that of other plants, and to provide an indication of the possible need to adjust priorities and resources to achieve improved overall performance. WANO performance indicators are intended to support the exchange of operating experience information and to allow consistent comparisons of nuclear plant performance. It is expected that WANO performance indicators will encourage emulation of the best industry performance and motivate the identification and exchange of good practices in nuclear plant operation.

This report considers WANO PIs values assessment of power units/stations as well as initial data obtained from NPPs and stored in the DES database. The PIs considered are as follows:

- **UCF** - Unit Capability Factor;
- **UCLF** - Unplanned Capability Loss Factor;
- **FLR** - Forced Loss Rate;
- **GRLF** - Grid Related Loss Factor;
- **UA7** - Unplanned Automatic Scrams per 7000 Hours Critical;
- **US7** - Unplanned Scrams per 7000 Hours Critical;
- **SSPI** - Safety System Performance Indicator;
- **FRI** - Fuel Reliability Indicator;
- **CRE** - Collective Radiation Exposure;
- **CPI** - Chemistry Performance Indicator;
- **ISA2** - Industrial Safety Accident Rate;
- **CISA2** - Contractor Industrial Safety Accident Rate;
- **TISA2** - Total Industrial Safety Accident Rate.

This report contains PI values as of the end of 2017 (2017Q4). All values are counted following a 36 months' calculation cycle, except for FRI data, which values are calculated following a 12 months' calculation cycle. Analytical data is provided in 5 main sections of this report and in appendix.

Section 1 contains overall performance data of all WANO Moscow Center NPPs over 2017.

Section 2 shows current perspective (as of the end of 2017) of the key PIs long-term targets achievement. Graphs show the trends of long-term targets (both individual and industrial) achievement throughout the reporting period. The data is provided for stations of WANO MC as well as for the other regional centres.

Section 3 contains WANO Index analysis results. General recommendations for all stations of WANO Moscow Center are provided as well.

Section 4 contains full analysis of WANO PIs for the Moscow Center of WANO. This part also provides the median values history and worse quartile boundary values for WANO PIs of MC.

Section 5 contains reporting outputs on implementation of WANO PI Programme at WANO MC in 2017.

Appendix 1 provides histograms of all WANO PIs for Moscow Center as of the 4th quarter of 2017.

1. WANO MC Total Performance Indicators for 2017

As of the end of 2017 the WANO MC PI database included 74 power units (2 new units: Beloyarsk NPP 4 and Novovoronezh NPP 2-1 were added to the database) operated by 25 NPPs. As well 5 nuclear vessels operated by FSUE Atomflot were included into the PI database in 2017. Distribution of power units by the types of reactor facilities is as follows:

VVER-1000 – 33;
VVER-1200 – 1
VVER-440 – 23;
RBMK-1000 – 11;
EGP-6 – 4;
FB-600 – 1;
FB-800 – 1;
Atomflot – 5 nuclear vessels.

Table 1 contains WANO MC general data for 2017, based on the NPPs data submitted to the WANO PI Programme database.

Table 1

Item No	Parameter	Units of measurement	Value
1	Reference unit power*	GW	58,913
2	Total potential generation	TW/h	506,7
3	Total actual generation	TW/h	409,9
4	Planned energy loss	TW/h	82,0
5	Unplanned outage extension energy loss	TW/h	1,6
6	Unplanned forced energy loss	TW/h	13,3
7	Grid instability energy loss	TW/h	0,025
8	Number of unplanned automatic scrams	times	9
9	Number of unplanned manual scrams	times	3
10	Planned unavailable hours for safety systems	hour	18879
11	Unplanned unavailable hours for safety systems	hour	3289
12	Fault exposure unavailable hours for safety systems	hour	2228
13	Total external whole body exposure	man*Sv	60,13
14	Total internal whole body exposure	man*Sv	0,113
15	Total collective radiation exposure	man*Sv	60,24

Item No	Parameter	Units of measurement	Value
16	Number of restricted-time accidents	times	6
17	Number of lost-time accidents	times	41
18	Number of work-related fatalities for utility	times	1

*** the value of reference unit power is lower, due to works on raise of reference power conducted at several power units, and these are only the initial design values which are reported to DES system.**

****the reference power of five nuclear vessels of FSUE Atomflot is not taken into consideration**

2. Meeting the WANO KPI Long-Term Targets

This section of the report provides current perspective of meeting the WANO key performance indicators long-term targets (both individual and industrial). The results as of the end of 2017 and overall performance figures of WANO Moscow Center for the entire reporting period are provided.

WANO Performance Indicators **individual targets** are the values chosen to monitor individual units/stations in order to track the trends of performance improvement. The **industry targets** are the values chosen to allow for proper monitoring of the entire world nuclear field and for analysis of individual input made by a single NPP.

The meaning of a target is not a hard target which must be pursued with high priority and to which hard commitment is required, but more a target which allows individual operators to determine a "gap" and to define actions to close the gap.

The reference will be helpful to identify "plants in need of assistance" and trend analyses per centre and worldwide to give direction to coordinated programs to support the pursuit of excellence.

The individual unit or station performance targets are based on a 100% units and stations achieving results that are better than the 2007 lowest quartile values.

The **industry-level** targets are based on 75% of units achieve an indicator value better than that achieved by only 50% of units (median) in 2007. This would mean that overall industry performance has improved, with an additional one-fourth of the industry units or stations achieving performance indicators results better than the 2007 industry median.

Key (Target) Performance Indicator selected for monitoring:

FLR – Forced Loss Rate;
SSPI – Safety System Performance Indicator, including safety systems as follows: high pressure safety injection system (**SP1**), core decay heat removal system (**SP2**) and emergency AC power supply system (DG) (**SP5**);
US7 – Unplanned Scrams per 7000 Hours Critical;
CRE – Collective Radiation Exposure;
TISA2 – Total Industrial Safety Accident Rate.

Table 2 presents boundary values of key PIs long-term targets set to be achieved before 2020.

Table 2

INDICATOR	UNIT	INDIVIDUAL TARGET	INDUSTRY TARGET
Operating Period Forced Loss Rate (FLR)	Percent (%)	5.0	2.0
Collective Radiation Exposure (CRE)	Man/Sievert	PWR: 0.9	PWR: 0.7

INDICATOR	UNIT	INDIVIDUAL TARGET	INDUSTRY TARGET
		LWCGR: 3.2	LWCGR: 2.4
Safety system performance indicator (SSPI)	number	SP1 and SP2: 0.020 SP5: 0.025	100% of worldwide units achieve the individual targets
Unplanned scrams per 7000 hours critical (US7)	Rate	1.0	0.5
Total industrial safety accident rate (TISA)	Number per 200,000 hours worked	0.5	0.2

Tables 3 and 4 present current perspective of WANO Moscow Center's progress in achievement of long-term targets (individual and industrial accordingly) as of the end of 2017.

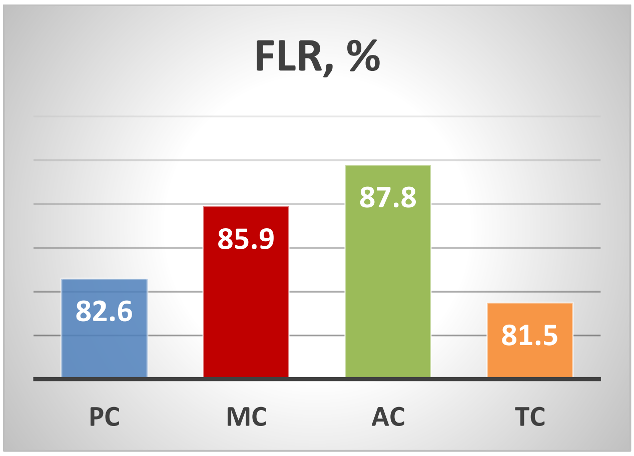
Fig. 1 and **2** present the comparison of regional centres by number of power units attaining the long-term targets as of the end of 2017.

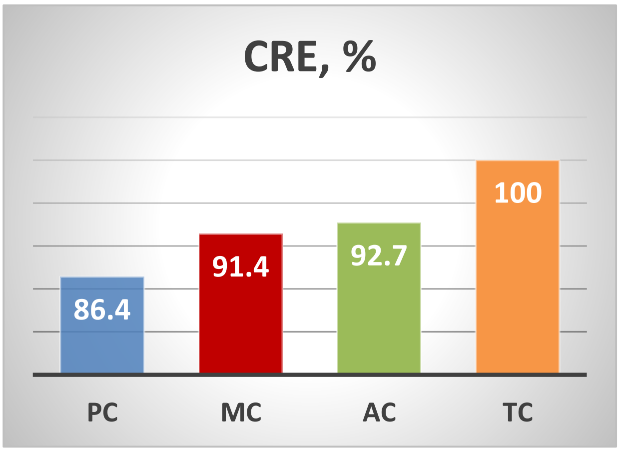
Table 3

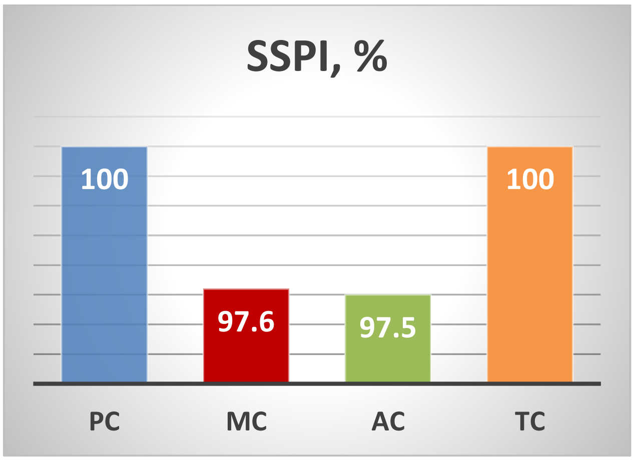
WANO Moscow Centre, 17Q4			
Individual target achievement			
Key indicator	**# of units with qualified results**	**# of units achieving target**	**% of units/NPP in regional centre, achieving target**
FLR (Forced Loss Rate)	**71**	**61**	**85,9%**
CRE (Collective Radiation Exposure)	**70**	**64**	**91,4%**
TISA (Total Industrial Safety Accident Rate)	**25**	**24**	**96%**
US7 (Unplanned Scrams per 7000 Hours critical)	**70**	**68**	**97,1%**
SSPI (Safety System Performance Indicator)	**165**	**161**	**97,6%**

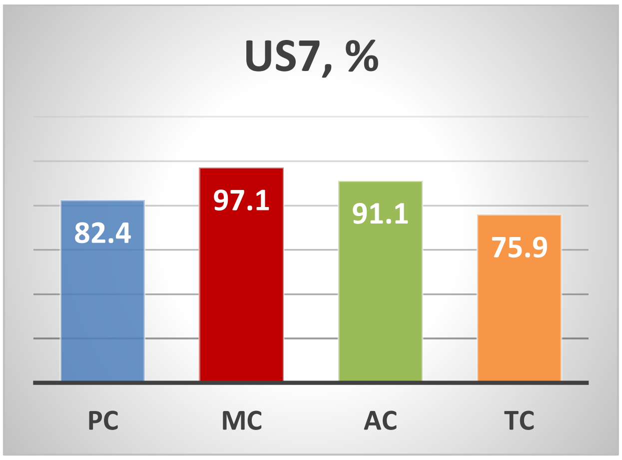
Table 4

WANO Moscow Centre, 17Q4			
Industry target achievement			
Key indicator	**# of units with qualified results**	**# of units achieving target**	**% of units/NPP in regional centre, achieving target**
FLR (Forced Loss Rate)	**71**	**45**	**63,4%**
CRE (Collective Radiation Exposure)	**70**	**50**	**71,4%**
TISA (Total Industrial Safety Accident Rate)	**25**	**20**	**80%**
US7 (Unplanned Scrams per 7000 Hours Critical)	**70**	**58**	**82,9%**
SSPI (Safety System Performance Indicator)	**165**	**66**	**94,3%**









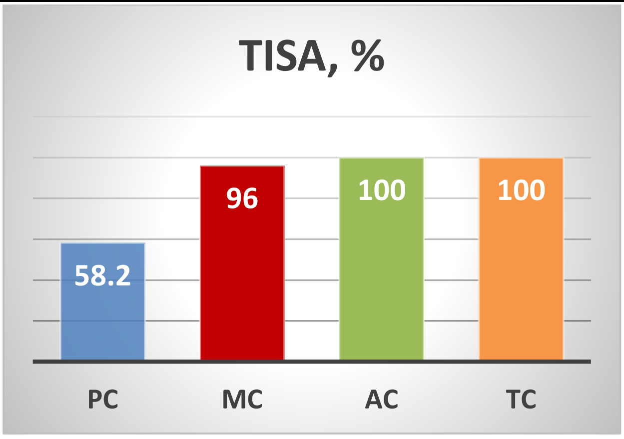
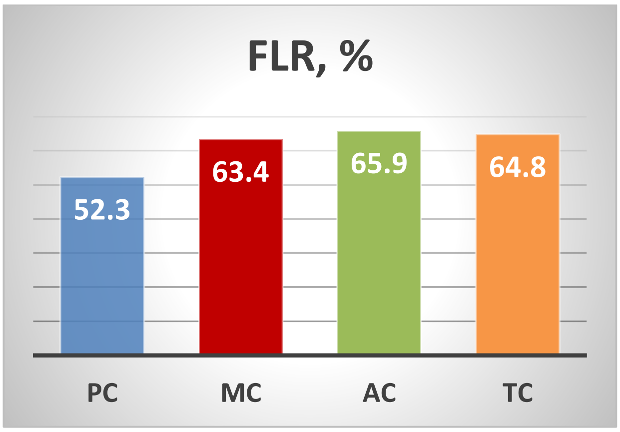
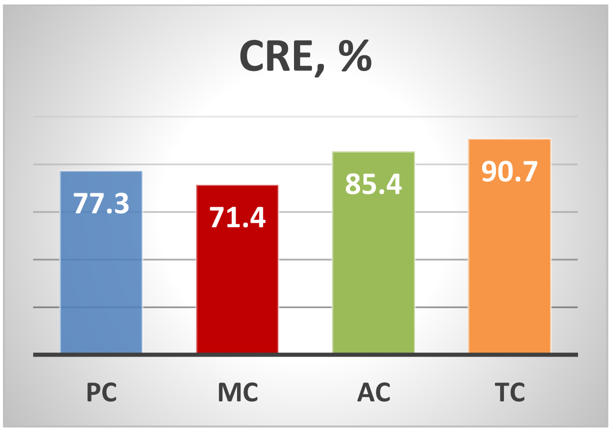
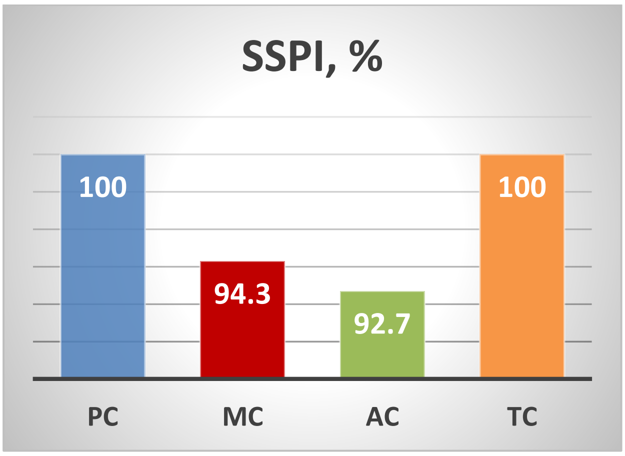
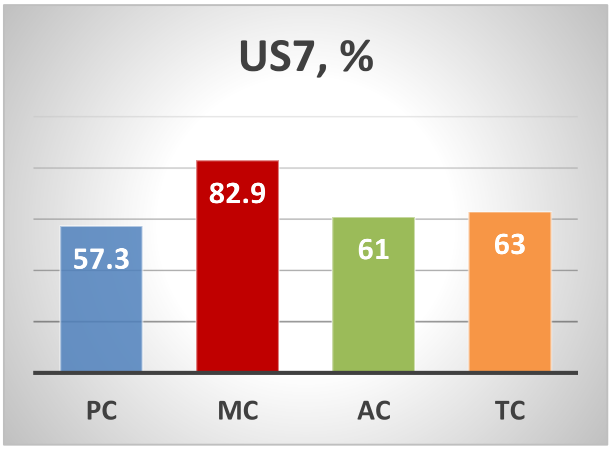


Fig.1 The percentage ratio of power units attaining the individual KPI targets by the WANO Regional Centres as of the end of 2017









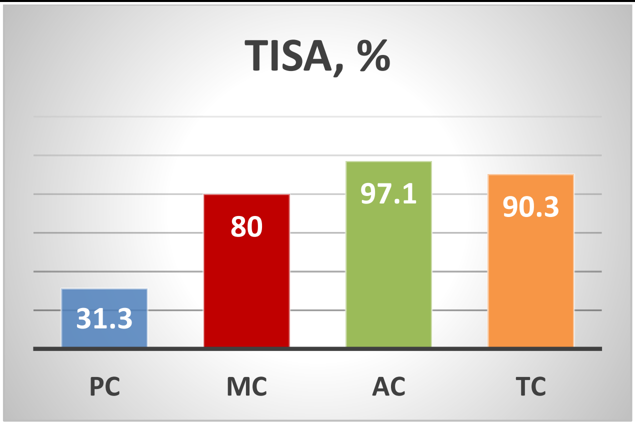


Fig. 2 The percentage ratio of power units attaining the individual KPI targets by the WANO Regional Centres as of the end of 2017

Fig. 3 ÷ 5 present the trends comparison of the KPIs long-term targets achievement within WANO MC throughout the history of a "long-term target" concept (since 2008 up to 2017).

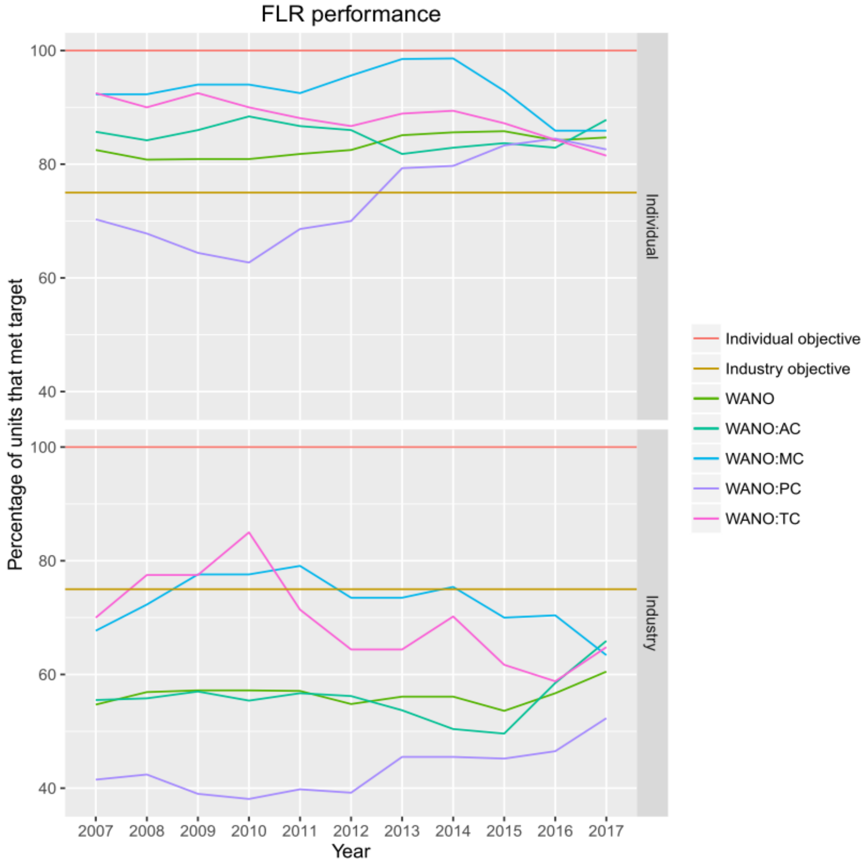
The key performance indicators encompass all main aspects of operation. The indicators with the set target values serve to point out the direction towards performance improvement.

As compared with the end of 2016 the progress of individual targets achievement within the Moscow Centre has a descended trend as for the following indicators: forced loss rate (**FLR**) and total industrial safety accident rate (**TISA**). The values have decreased by 1,2% and 1% accordingly. As for the unplanned scrams per 7000 hours critical (**US7**) and safety systems availability (**SSPI**) the situation has not changed (just a slight trend upwards within 0,1%). And a decent positive trend is observed in collective radiation exposure indicator (**CRE**) within 3%.

The progress of WANO MC power units in attaining the industrial targets differs. For a negative trend is present in the values of 3 indicators (**FLR, CRE, SSPI**), in comparison with the previous year, which decrease from 8% (**FLR**) to 1,5% (**CRE**) accordingly. The two rest indicators have a slight positive trend.

The reason of difference in progress of target values achievement could lay in a feeling that a certain level of stability has been reached (individual target) and in lack of pursue to more ambitious goals like performance excellence (industrial target).

Detailed information on KPIs is presented in section 4.



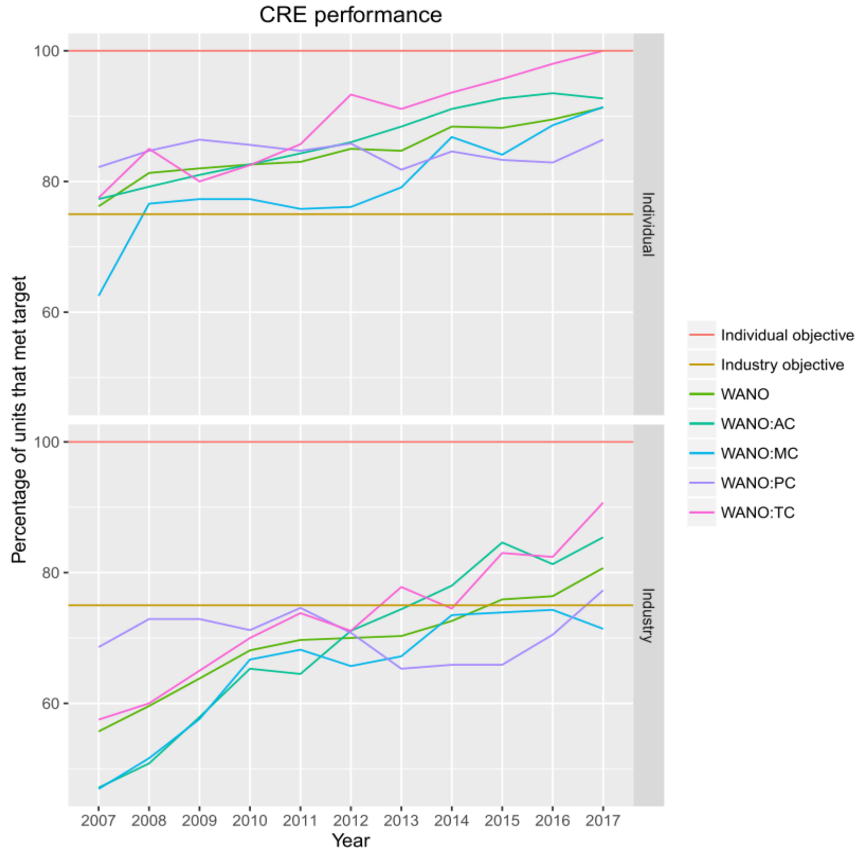
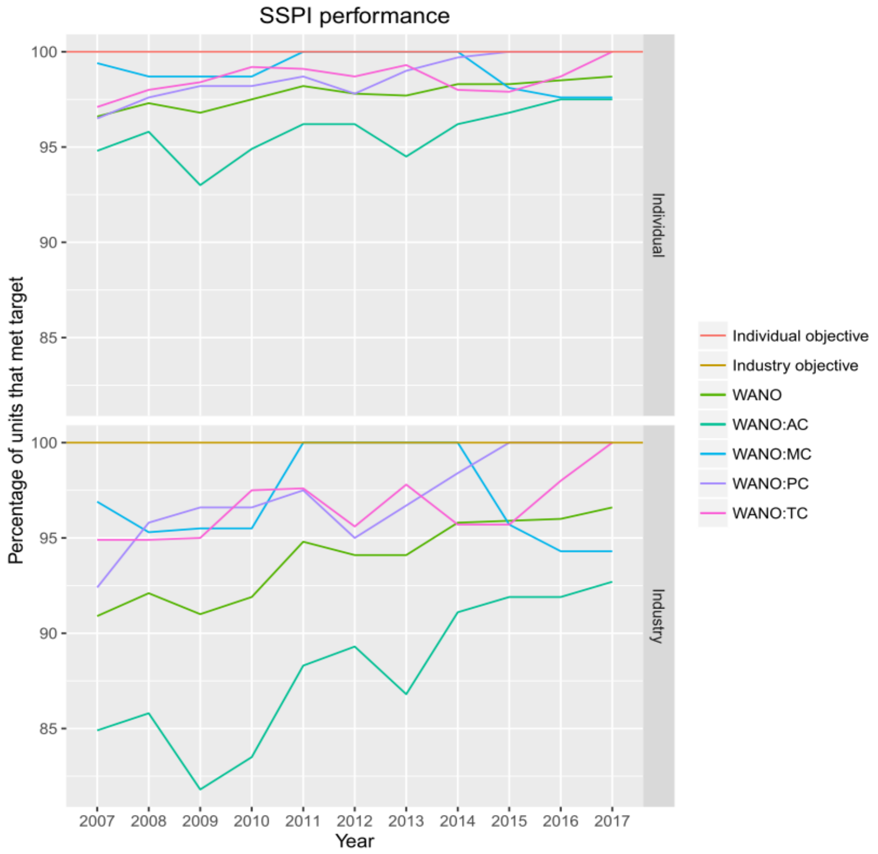


Fig. 3 KPIs trends of meeting individual and industrial targets within WANO MC over the whole reporting period (2007 – 2017) – indicators **FLR**, **CRE**



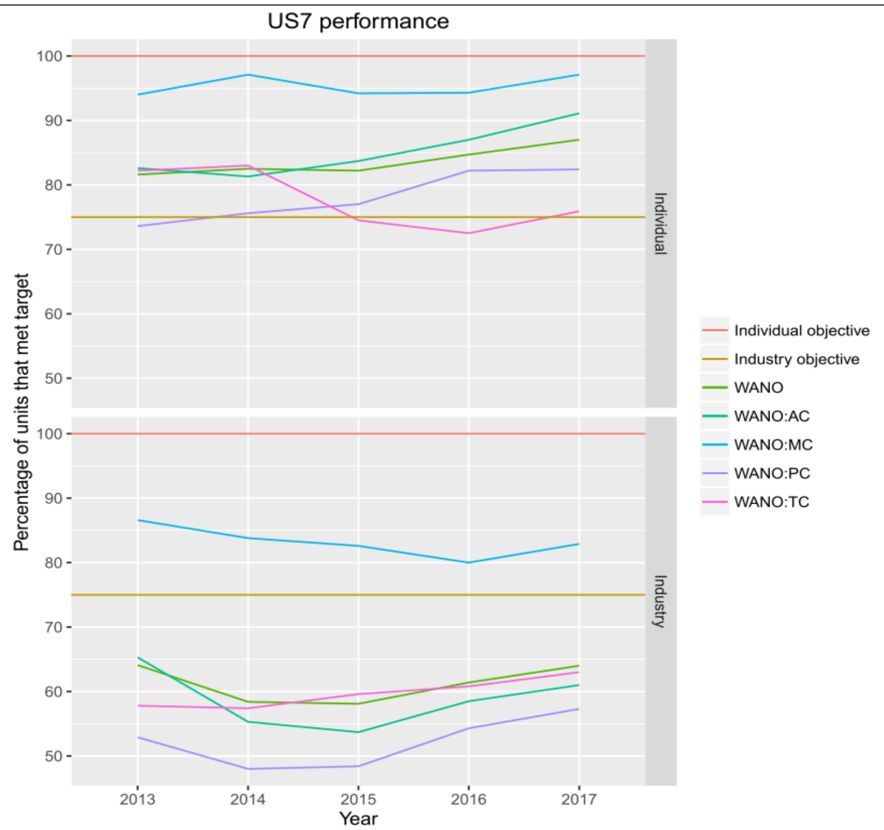


Fig. 4 KPIs trends of meeting individual and industrial targets within WANO MC over the whole reporting period (2007 – 2017) – indicators **SSPI**, **US7**

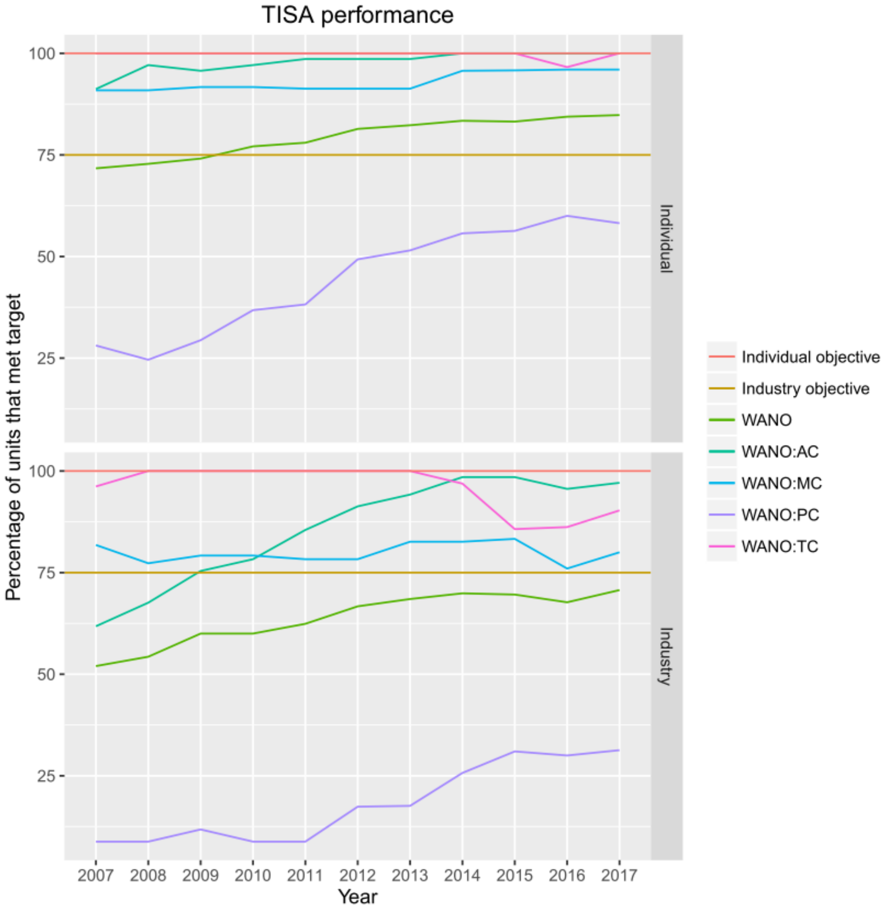


Fig. 5 KPIs trends of meeting individual and industrial targets within WANO MC over the whole reporting period (2007 – 2017) – indicator **TISA**

3. WANO Index analysis results

3.1. Overall Figures of WANO Index Analysis

A new overall performance indicator of NPPs - **WANO Index** was developed to allow a comprehensive assessment of operational safety level in WANO. WANO Index is a significant indicator for trends analysis and comparison of plants performance. It is a kind of an express-indicator of current perspective of industrial safety status at NPP and allows to identify the main operational areas needed detailed monitoring.

Its value is counted based on numerous inputs (10 basic WANO performance indicators) and is reported as an overall index. **Table 5** contains performance indicators considered for WANO index and their basic calculation criteria (calculation cycle, weighting factor). Index is counted for individual unit/station, utility and is limited to 100 points (higher number means better performance).

Table 5

INDICATOR	PERIOD	WEIGHING FACTOR	MAXIMUM POINTS
CRE, Collective Radiation Exposure of the Personnel	24	0.10	10
CPI, Chemistry Performance Indicator	24	0.05	5
FLR, Forced Loss Rate	24	0.15	15
FRI, Fuel Reliability	12	0.10	10
ISA2, Lost Time Accidents (for 200,000 working hours)	24	0.05	5
SP1, Safety Systems Performance	36	0.10	10
SP2, Safety Systems Performance	36	0.10	10
SP5, Safety Systems Performance	36	0.10	10
UA7, Unplanned Scrams	24	0.10	10
UCF, Unit Capability Factor	24	0.15	15
Total weighting points			**100**
Total reference points			**100**

WANO index is used as a single value giving overall characteristics of plant performance, and in addition to this it allows for assessment of specific production areas in need of improvement by strengthening attention to or increasing focus on them. For the purpose of WANO and its Members performance assessment the overall performance indicators index, a.k.a. "index", is counted for the power units within WANO.

Fig. 6 shows WANO index values over regional centres by the end of 2017, and **fig. 7** gives charts of WANO index history at regional centres over the last 5 years.

Comparison of the WANO MC index median values with the similar ones of other WANO regional centres shows that MC takes third place after AC and TC. WANO methodology doesn't allow for comprehensive comparison of index values due to variety of reactor types in regional centres. But still it is possible to compare the index values history for a certain period. A trend to slight WANO MC index value decrease is observed since 2014. In case of keeping this speed of change the WANO MC index value is likely to reach its value of five years ago by beginning of 2017, which testifies for decrease of operational safety level at Moscow Center NPPs or for significant energy losses occurred for any reason.

Fig. 8 shows WANO index median values of WANO MC Member Organizations.

Fig. 9 shows in more details WANO index values for all the power units of Moscow Centre, reporting performance data to the performance indicators database (except for Beloyarsk NPP, for which units the index is not counted). Quartile values shown on this histogram are colored to enable better visual perception. The best quartile (green color) values are ranging from 94,1 to 100 points. As of the end of 2017 only **3** WANO MC power units reach maximum index value (100 points).

The quartile way to organize statistical data enables identifying stations with the worst and the best results. In order to assess the actual plant operation safety status, it is recommended to perform data analysis of each individual unit identifying its quartile's data for a certain period.

An important feature of WANO Programme "performance indicators" is that units are added to the database only after they get commissioned. This affects the reporting WANO index value, which relies on data of various reporting cycles (from 18 up to 36 months).

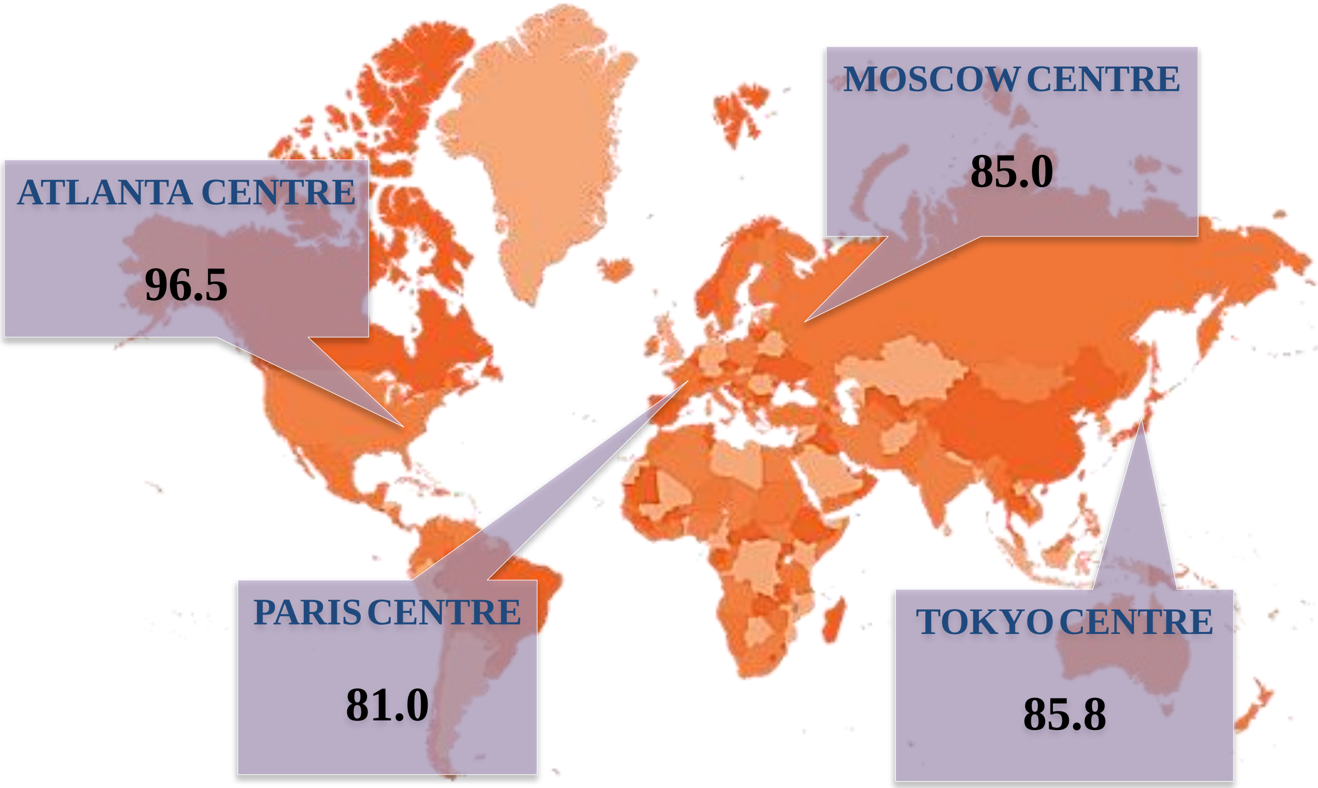


Fig.6 WANO Index median values achieved by regional centers by the end of 2017

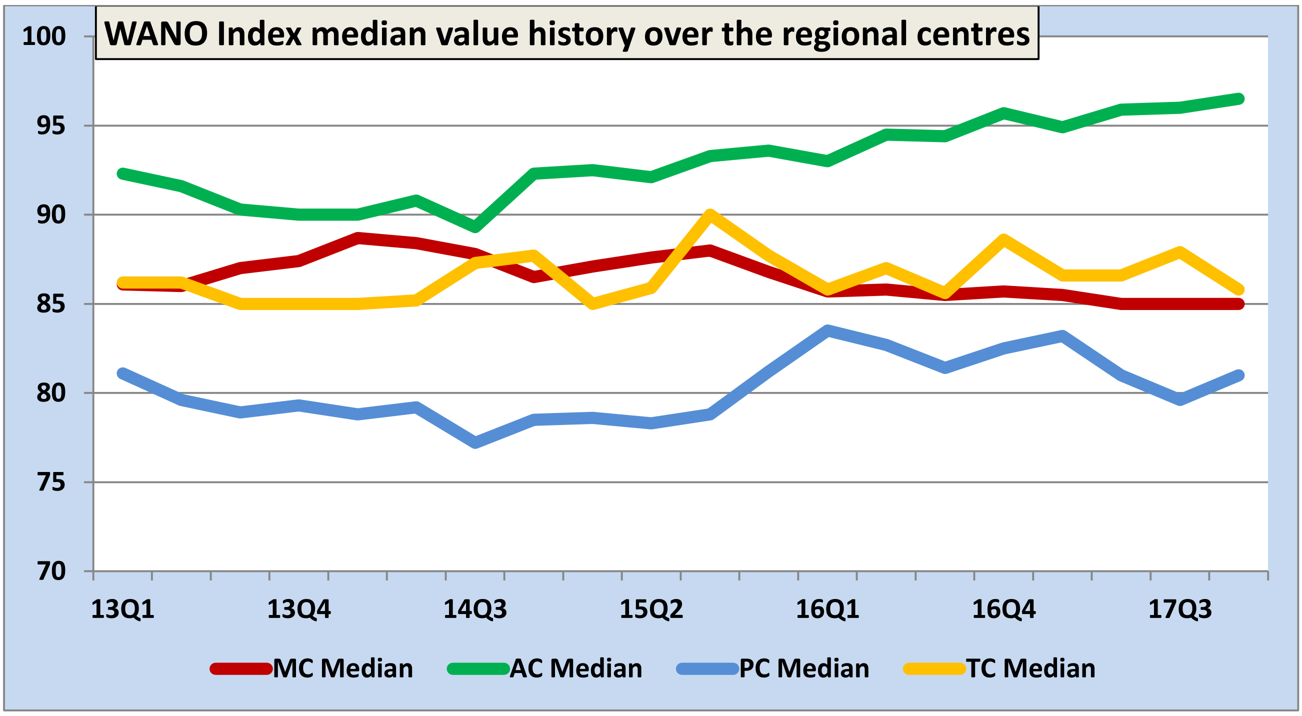


Fig.7 WANO Index median values history over the regional centres over the period 2013 – 2017

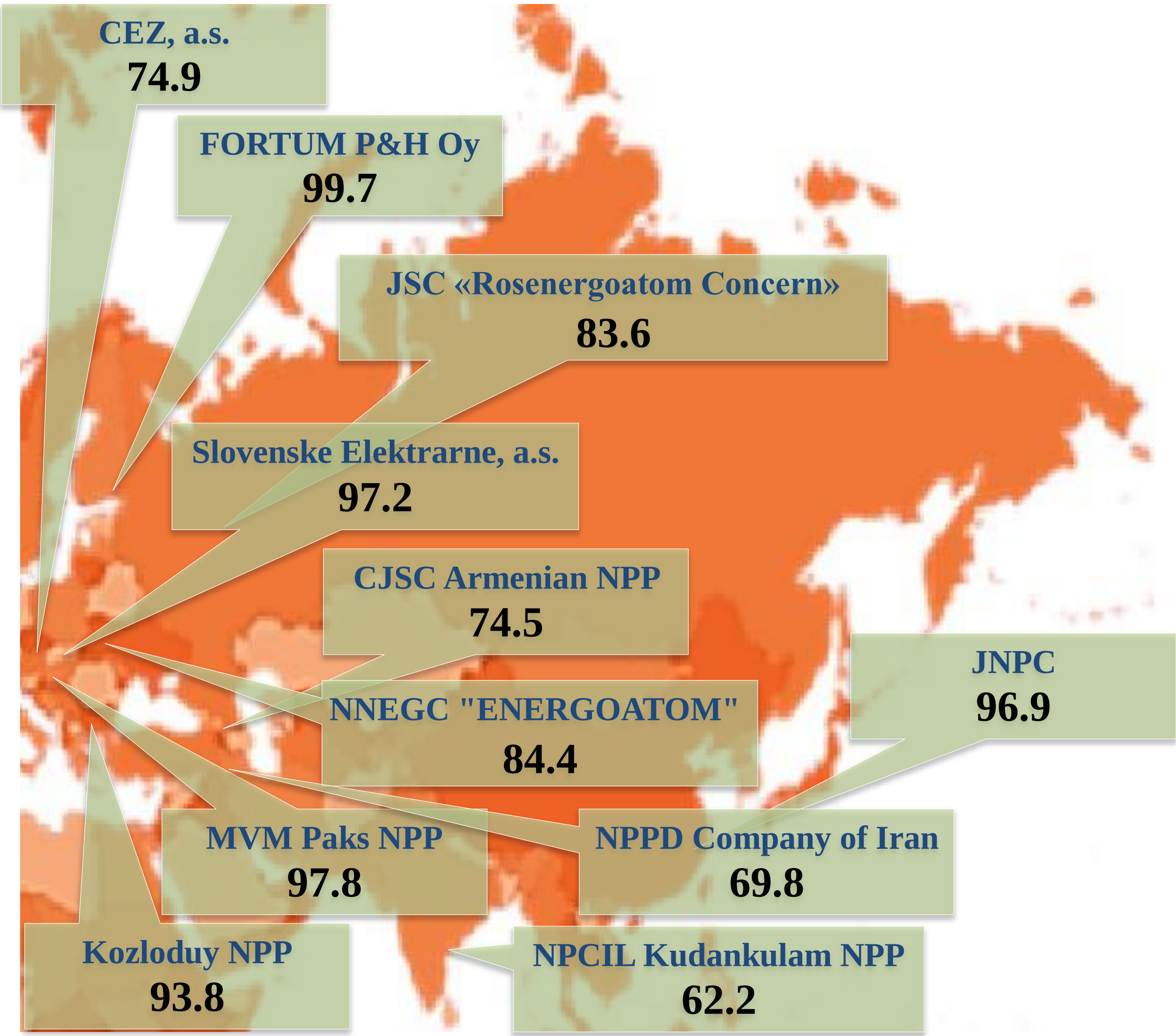


Fig.8 WANO Index Median values for WANO Member Organizations as of the end of 2017

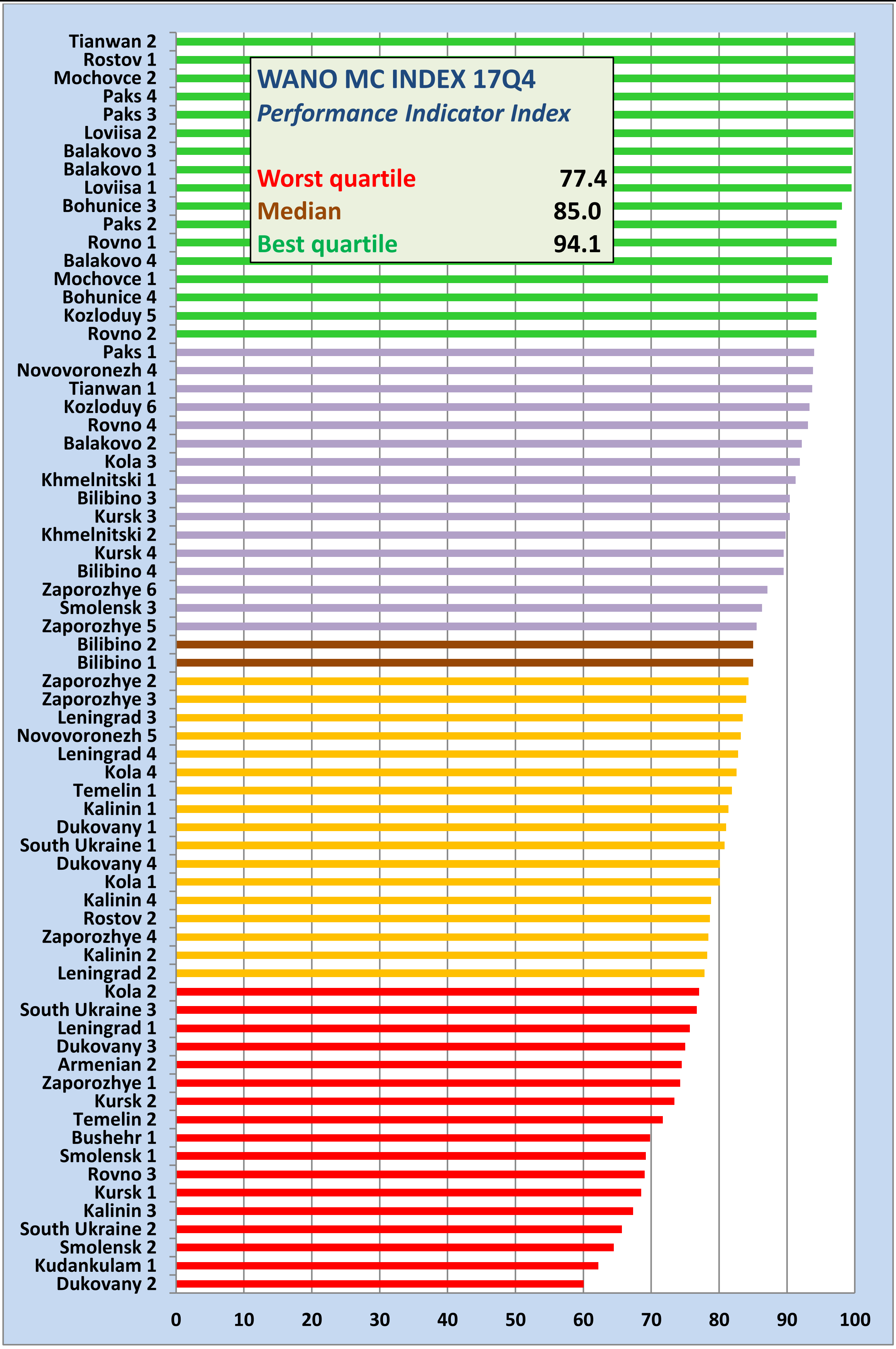
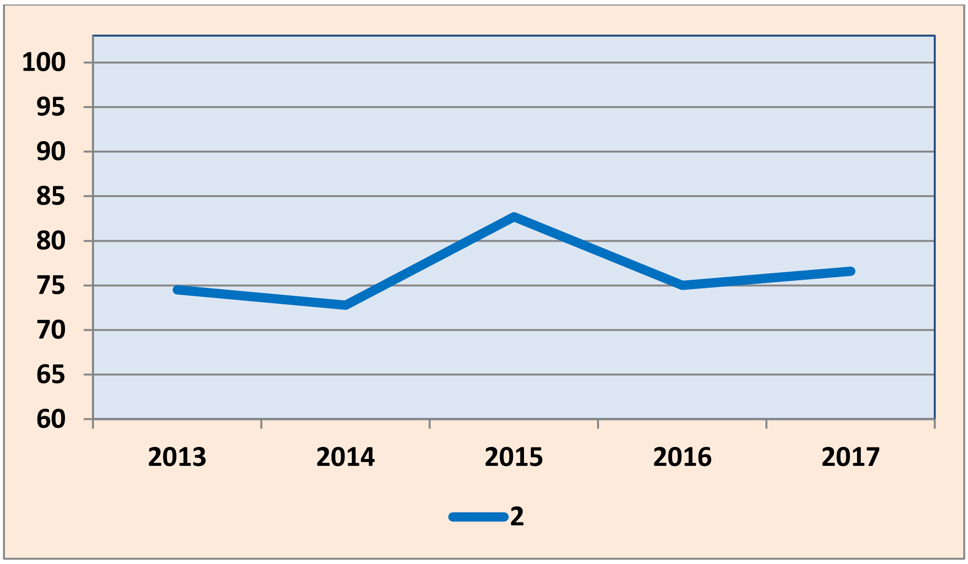


Fig.9 Distribution of index values by WANO – MC power units as of the end of 2017.

3.2. Analysis of WANO Index Values of Moscow Centre NPPs

This subsection contains information on 24 NPPs[1] of WANO Moscow Centre. It also provides WANO index value history charts and the NPP's mean value for these power units[2]. Tables contain data on contributing indicators, which decrease WANO index value. The data is presented for five-year period.

ARMENIAN NPP

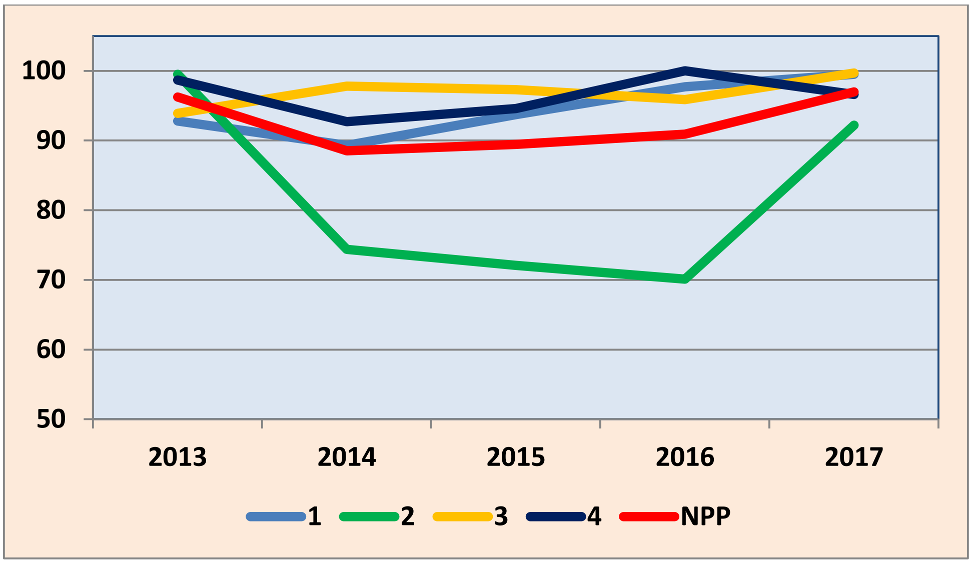


Unit	Year	Main contributors
2	2013	CRE, FLR, UCF
	2014	CRE, CPI, FLR, UCF
	2015	CRE, CPI, FLR, UCF
	2016	CRE, CPI, UCF
	2017	CRE, CPI, UCF

[1].WANO Index is not to be calculated for Beloyarsk NPP and FSUE Atomflot

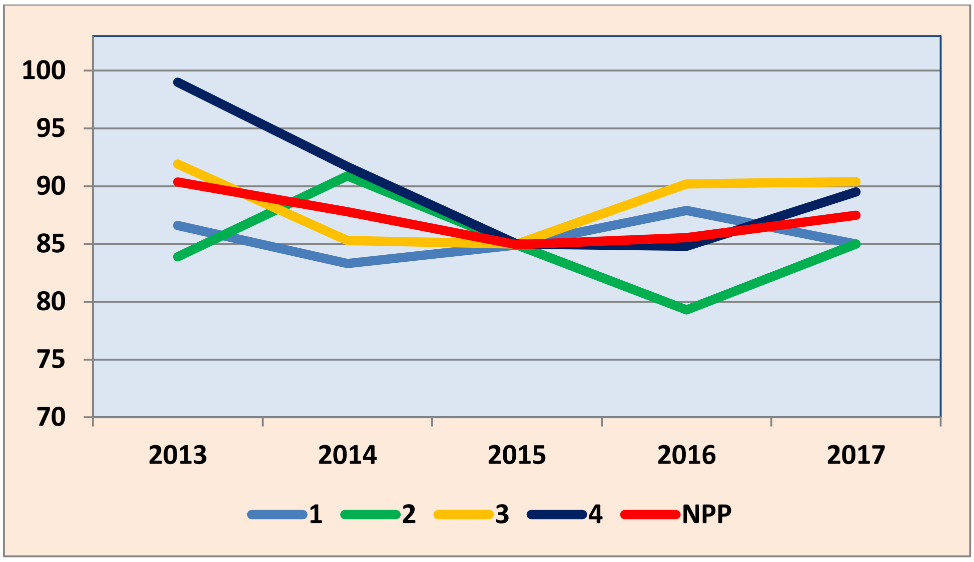
[2] Mean value of one-unit station equals mean value of a power unit.

BALAKOVO NPP



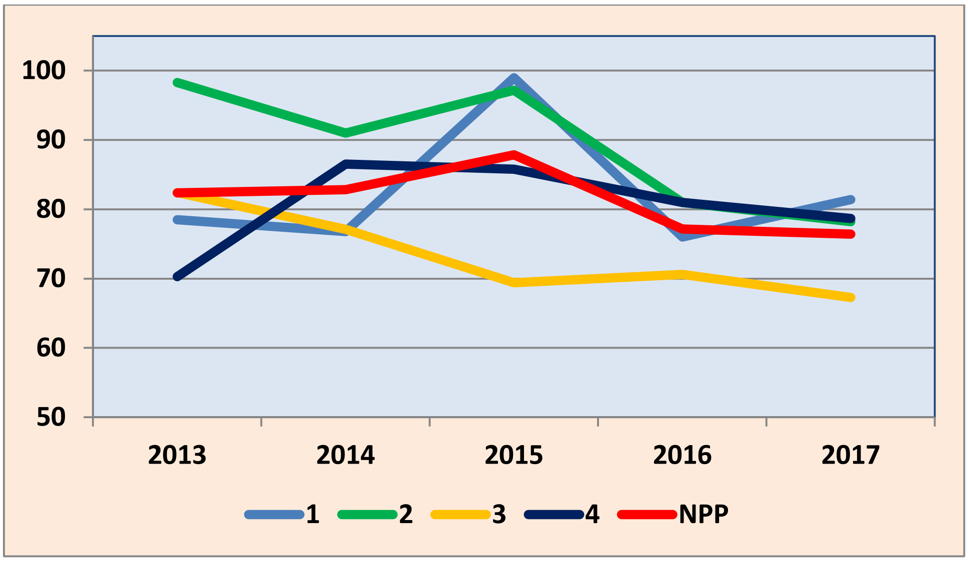
Unit	Year	Main contributors
1	2013	UCF
	2014	FRI, UCF
	2015	FRI, UCF
	2016	UCF
	2017	CRE, FLR
2	2013	CPI
	2014	CPI, FLR, UCF
	2015	CPI, FLR, UCF
	2016	FLR, UCF
	2017	CRE, UCF
3	2013	UCF
	2014	UCF
	2015	FRI, UCF
	2016	UCF
	2017	CRE
4	2013	CPI, FLR
	2014	CPI, UCF
	2015	UCF
	2016	-
	2017	CRE, UCF

BILIBINO NPP



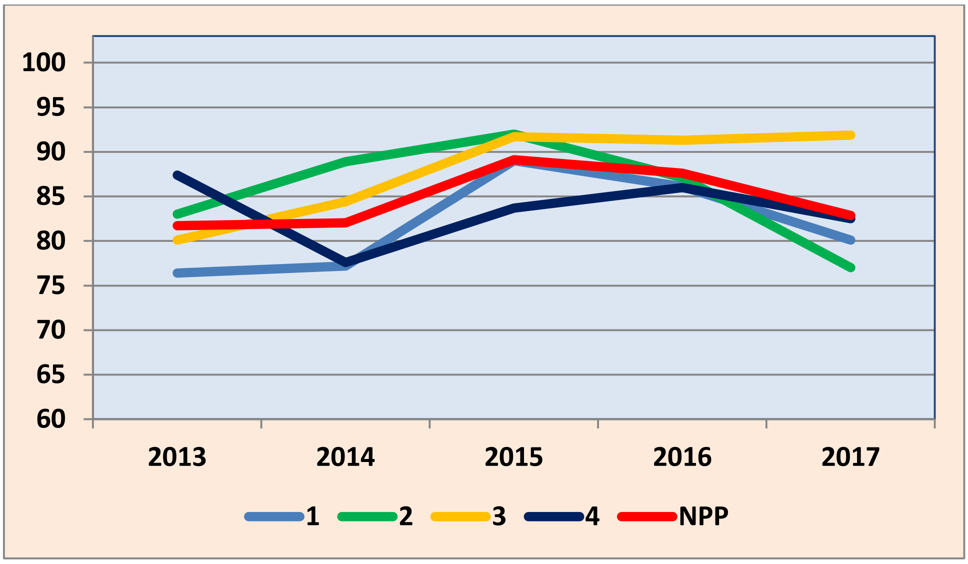
Unit	Year	Main contributors
1	2013	CPI, UA7, UCF
	2014	FLR, UA7, UCF
	2015	FLR, UCF
	2016	UCF
	2017	UCF
2	2013	CPI, UCF
	2014	UCF
	2015	UA7, UCF
	2016	UCF
	2017	UCF
3	2013	UCF
	2014	UCF
	2015	UCF
	2016	UCF
	2017	UCF
4	2013	UCF
	2014	UCF
	2015	UCF
	2016	UCF
	2017	UCF

KALININ NPP



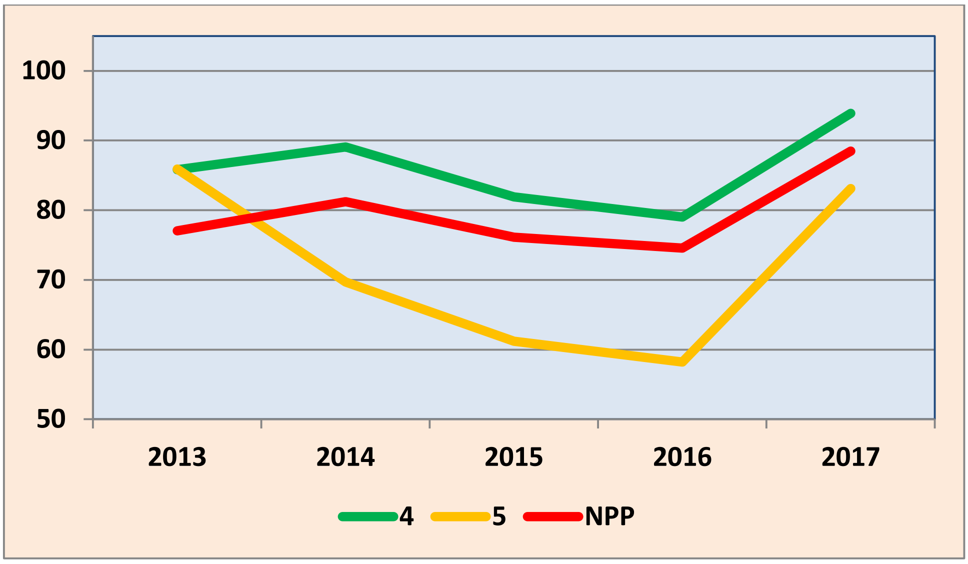
Unit	Year	Main contributors
1	2013	CPI, FLR, UCF
	2014	FLR, UA7, UCF
	2015	CPI, FLR
	2016	CRE, CPI, FLR, UCF
	2017	CRE, FRI, FLR, UCF
2	2013	CPI, UCF
	2014	UCF
	2015	CPI, FLR, UCF
	2016	CRE, CPI, FLR, UCF
	2017	CRE, FLR, UCF
3	2013	CPI, FLR, UCF
	2014	FLR, UCF
	2015	CPI, FLR, UCF
	2016	CPI, FLR, UCF
	2017	FRI, FLR, UCF
4	2013	FLR, UCF
	2014	FLR, UCF
	2015	FLR, UA7, UCF
	2016	FLR, UCF
	2017	FLR, UCF

KOLA NPP



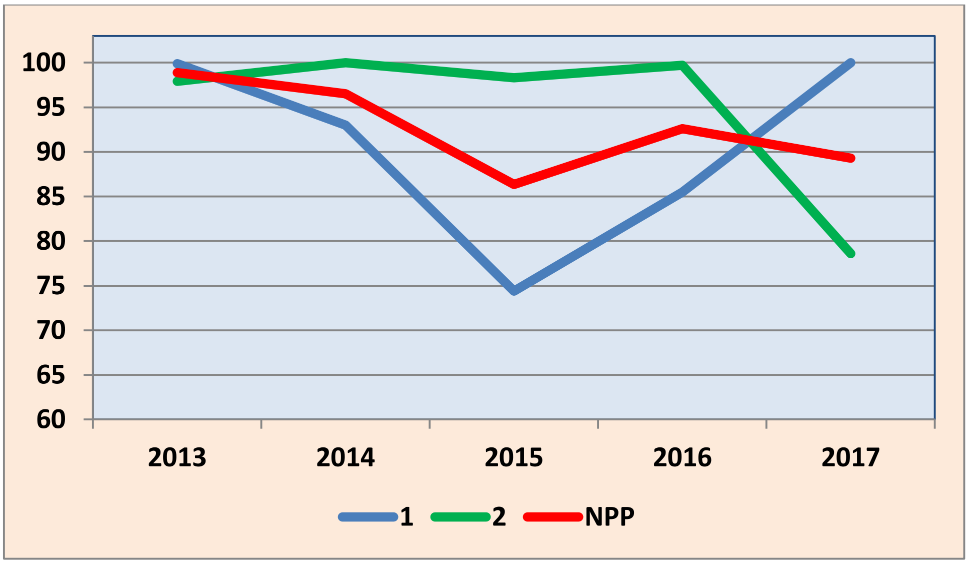
Unit	Year	Main contributors
1	2013	CRE, CPI, FLR, FRI, UA7, UCF
	2014	CRE, CPI, FLR, UCF
	2015	CRE, FRI, UCF
	2016	CRE, UCF
	2017	CRE, FRI, UCF
2	2013	CRE, CPI, FRI, UCF
	2014	CRE, CPI, FRI, UCF
	2015	CRE, FRI, UCF
	2016	CRE, FRI, UCF
	2017	FRI, UCF
3	2013	CRE, CPI, FLR, UCF
	2014	CRE, FLR, UCF
	2015	CRE, UCF
	2016	CRE, UCF
	2017	UCF
4	2013	CRE, CPI, UCF
	2014	CRE, CPI, FLR, UA7, UCF
	2015	CRE, FLR, UA7, UCF
	2016	CRE, UA7, UCF
	2017	FLR, UA7, UCF

NOVOVORONEZH NPP



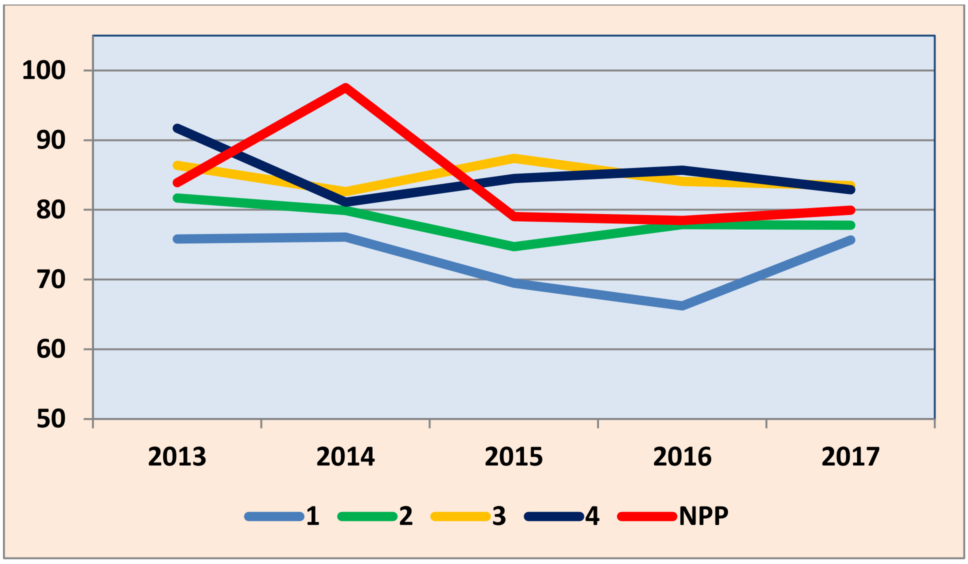
Unit	Year	Main contributors
4	2013	CRE, CPI, UCF
	2014	CRE, UCF
	2015	CRE, UCF
	2016	CRE, FLR, UCF
	2017	CRE, FLR, UCF
5	2013	CRE, CPI, FLR, UCF
	2014	CRE, CPI, FLR, UCF
	2015	CRE, CPI, FLR, UCF
	2016	CRE, CPI, UCF
	2017	CRE, FLR, UCF

ROSTOV NPP



Unit	Year	Main contributors
1	2013	FLR
	2014	CPI, FLR, UCF
	2015	CPI, FLR, UCF
	2016	CPI, FLR, UCF
	2017	-
2	2013	UCF
	2014	-
	2015	CPI, UCF
	2016	CPI, UCF
	2017	FLR, UCF

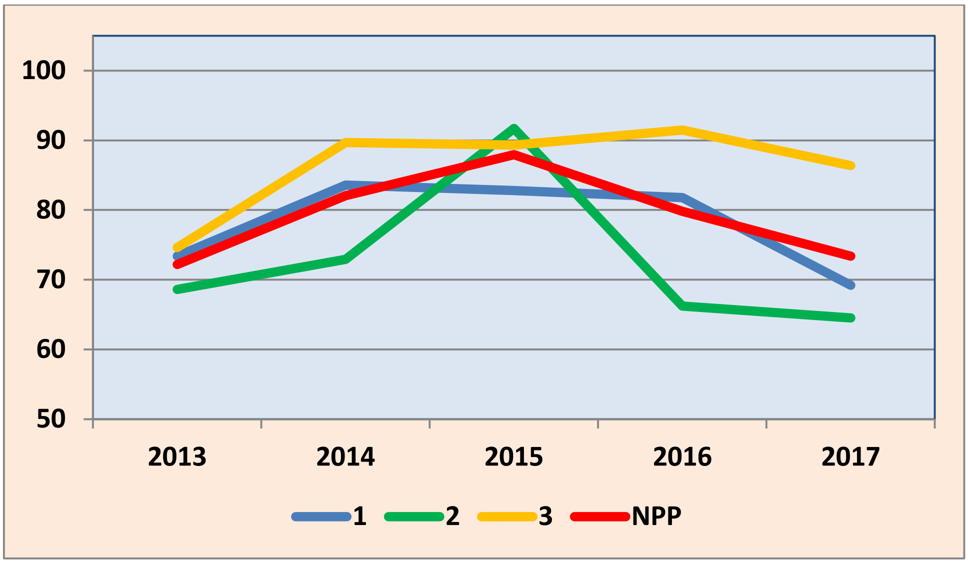
LENINGRAD NPP



Unit	Year	Main contributors
1	2013	CRE, FLR, UCF
	2014	CRE, FLR, FRI, UA7, UCF
	2015	CRE, FLR, FRI, UA7, UCF
	2016	CRE, FLR, FRI, UA7, UCF
	2017	CRE, FLR, UA7, UCF
2	2013	CRE, FLR, UCF
	2014	CRE, FRI, UCF
	2015	CRE, FLR, FRI, UCF
	2016	CRE, FLR, FRI, UCF
	2017	CRE, FLR, UCF
3	2013	CRE, FLR, FRI, UCF
	2014	CRE, FLR, FRI, UCF
	2015	CRE, FLR, FRI, UCF
	2016	CRE, FLR, FRI, UCF
	2017	CRE, FLR, FRI, UCF

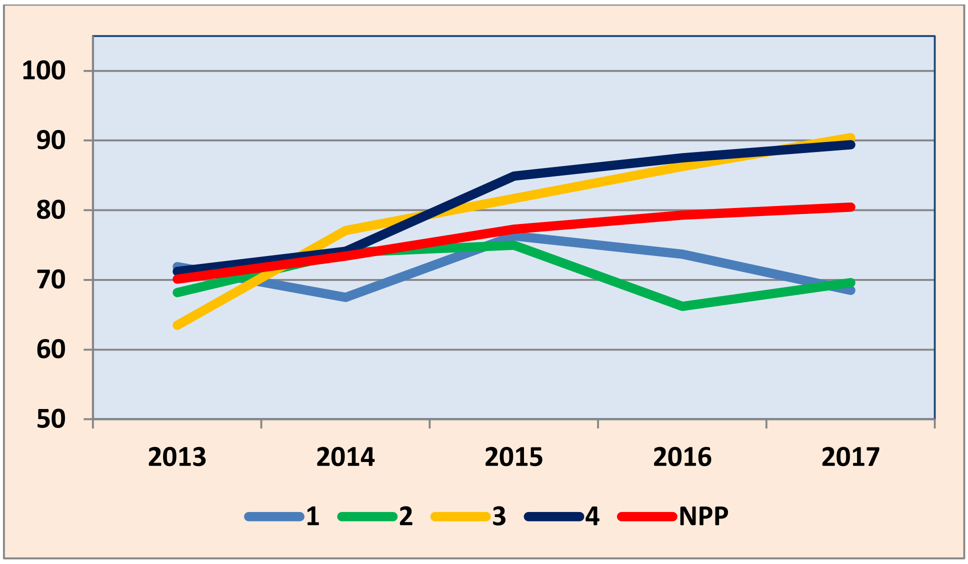
Unit	Year	Main contributors
4	2013	CRE, FLR, FRI, UCF
	2014	CRE, FLR, FRI, UA7, UCF
	2015	CRE, FLR, UCF
	2016	CRE, FLR, UCF
	2017	CRE, FLR, FRI, UCF

SMOLENSK NPP



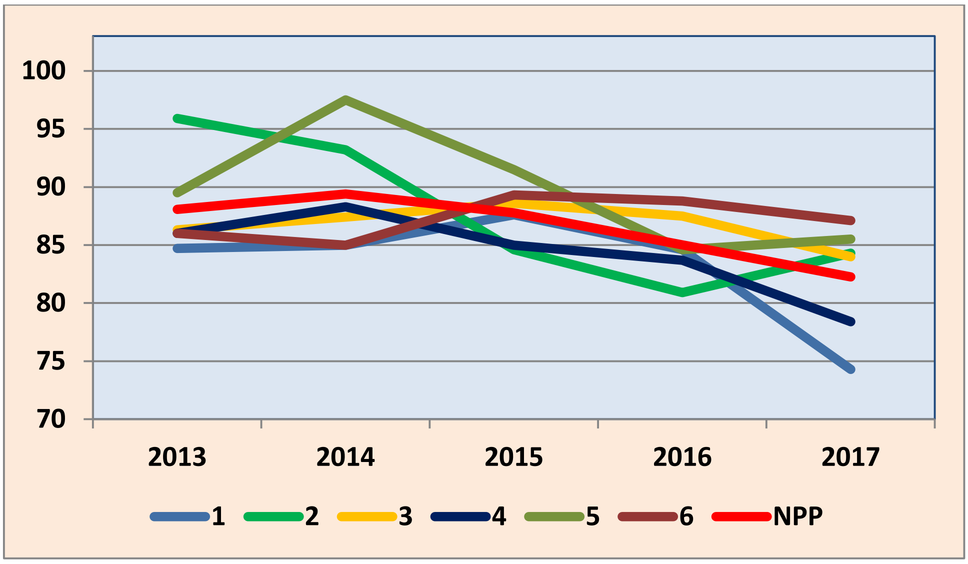
Unit	Year	Main contributors
1	2013	CRE, FLR, UA7, UCF
	2014	CRE, FLR, UA7, UCF
	2015	CRE, FLR, FRI, UCF
	2016	CRE, FLR, FRI, UCF
	2017	CRE, FLR, FRI, UCF
2	2013	CRE, FLR, UA7, UCF
	2014	CRE, FLR, FRI, UCF
	2015	CRE, FLR, FRI, UCF
	2016	CRE, FLR, FRI, UA7, UCF
	2017	CRE, FLR, FRI, UCF
3	2013	CRE, FLR, FRI, UCF
	2014	CRE, FLR, FRI, UCF
	2015	CRE, FRI, UCF
	2016	CRE, FLR, FRI, UCF
	2017	CRE, FLR, FRI, UCF

KURSK NPP



Unit	Year	Main contributors
1	2013	CRE, FLR, FRI, UA7, UCF
	2014	CRE, FLR, FRI, UCF
	2015	CRE, FLR, FRI, UCF
	2016	CRE, FLR, FRI, UA7, UCF
	2017	CRE, FLR, FRI, UA7, UCF
2	2013	CRE, CPI, FLR, UA7, UCF
	2014	CRE, FRI, UCF
	2015	CRE, FLR, FRI, UCF
	2016	CRE, FLR, FRI, UCF
	2017	CRE, FLR, FRI, UCF
3	2013	CRE, CPI, FLR, FRI, UCF
	2014	CRE, CPI, FLR, FRI, UCF
	2015	CRE, FLR, UCF
	2016	CRE, FRI, UCF
	2017	CRE, FRI, UCF
4	2013	CRE, CPI, FLR, FRI, UCF
	2014	CRE, CPI, FLR, FRI, UCF
	2015	CRE, FLR, FRI, UCF
	2016	CRE, UCF
	2017	CRE, FLR, UCF

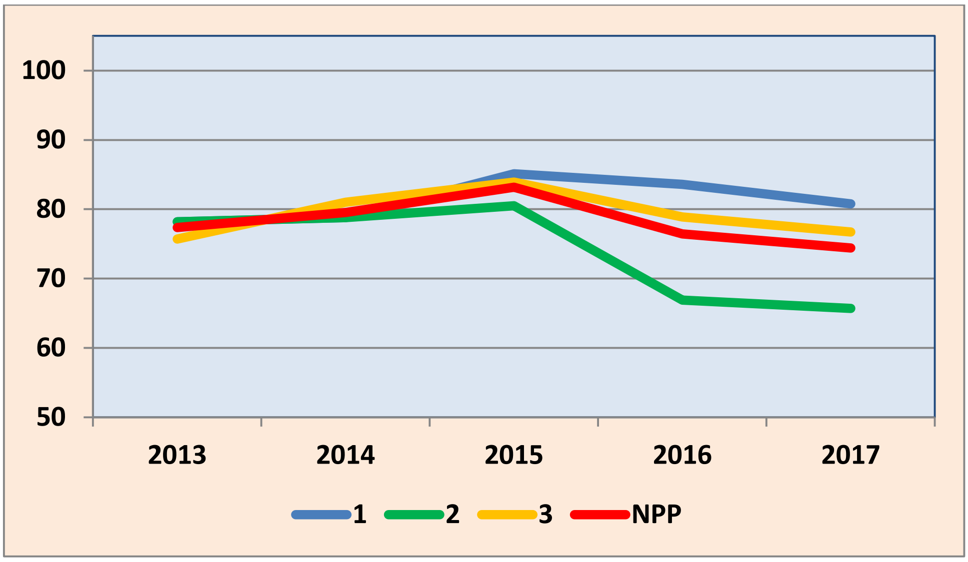
ZAPOROZHYE NPP



Unit	Year	Main contributors
1	2013	CPI, UCF
	2014	UCF
	2015	UCF
	2016	UCF
	2017	CRE, UCF
2	2013	UCF
	2014	UCF
	2015	UA7, UCF
	2016	UA7, UCF
	2017	CRE, UCF
3	2013	UCF
	2014	FLR, UCF
	2015	FLR, UCF
	2016	FLR, UCF
	2017	CRE, CPI, UCF
4	2013	UCF
	2014	FRI, UCF
	2015	UCF
	2016	UCF
	2017	CRE, FLR, UCF
5	2013	CPI, UCF
	2014	UCF
	2015	UCF
	2016	UCF
	2017	CRE, UCF
6	2013	UCF
	2014	UCF
	2015	UCF

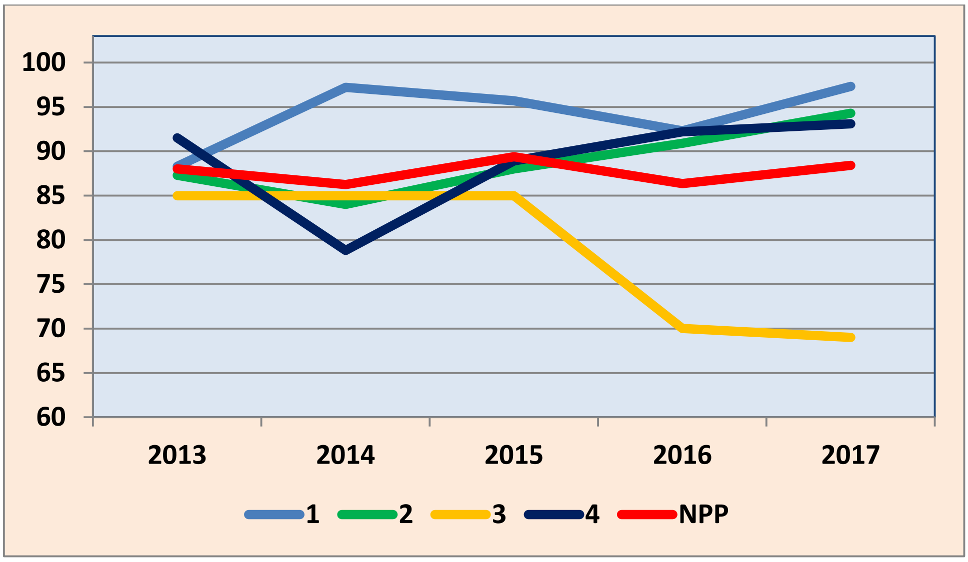
Unit	Year	Main contributors
	2016	UCF
	2017	CRE, FLR, UCF

SOUTH – UKRAINE NPP



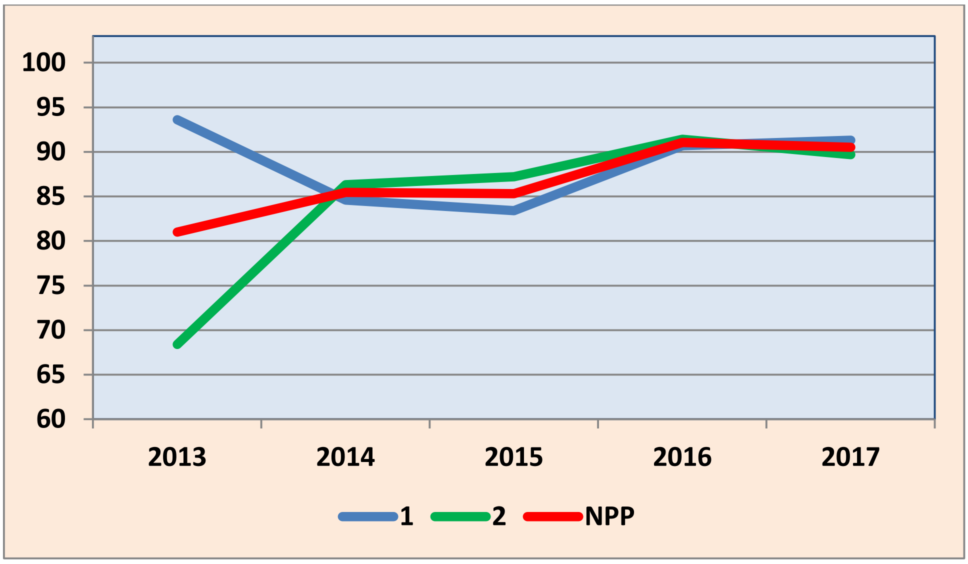
Unit	Year	Main contributors
1	2013	CRE, UCF
	2014	CRE, UCF
	2015	CRE, UCF
	2016	CRE, UCF
	2017	CRE, UCF
2	2013	CRE, UCF
	2014	CRE, UCF
	2015	CRE, UCF
	2016	CRE, FLR, UA7, UCF
	2017	CRE, FLR, UA7, UCF
3	2013	CRE, FLR, UA7, UCF
	2014	CRE, FRI, UCF
	2015	CRE, UCF
	2016	CRE, UCF
	2017	CRE, FLR, UA7, UCF

ROVNO NPP



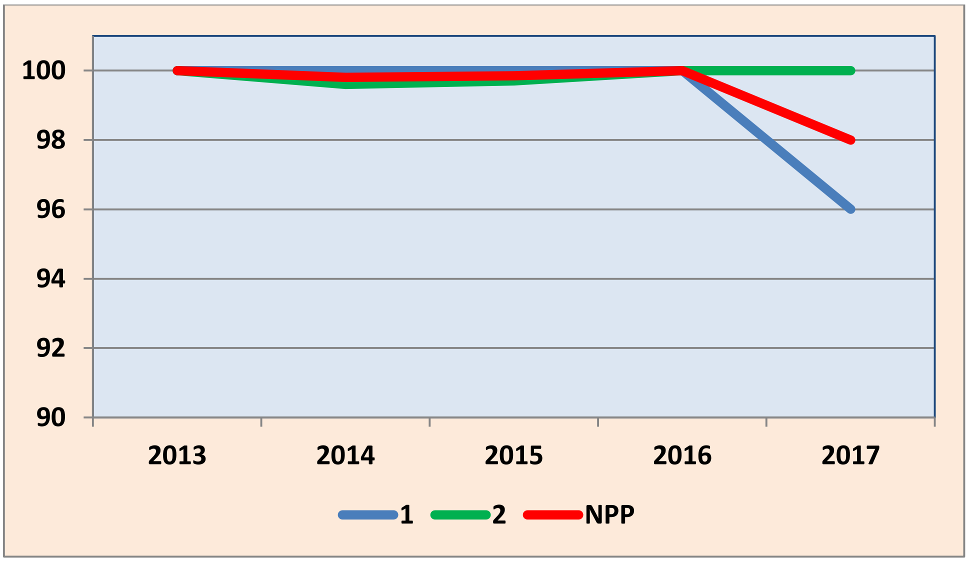
Unit	Year	Main contributors
1	2013	CRE, UCF
	2014	UA7, UCF
	2015	CRE, FRI, UCF
	2016	UCF
	2017	UCF
2	2013	CRE, FRI, UCF
	2014	FRI, UA7, UCF
	2015	CRE, UCF
	2016	UCF
	2017	UCF
3	2013	UCF
	2014	UCF
	2015	UCF
	2016	FLR, FRI, UCF
	2017	FLR, UA7, UCF
4	2013	UCF
	2014	FRI, UCF
	2015	UCF
	2016	UCF
	2017	UCF

KHMELNITSKI NPP



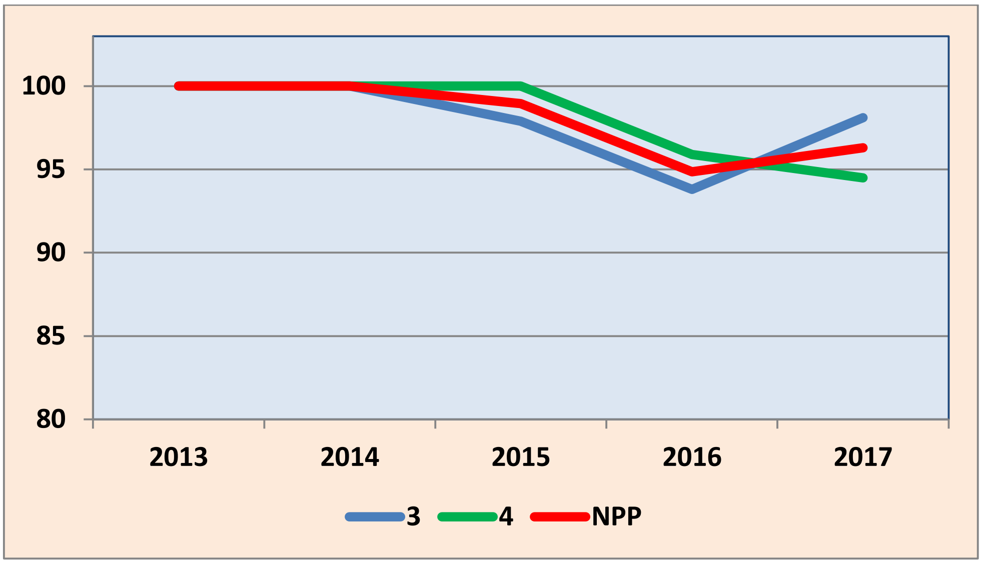
Unit	Year	Main contributors
1	2013	UCF
	2014	FLR, UCF
	2015	FLR, FRI, UCF
	2016	FLR, UCF
	2017	CRE, UCF
2	2013	CPI, FLR, FRI, UCF
	2014	CPI, UCF
	2015	CPI, UCF
	2016	CPI, UCF
	2017	CRE, CPI, UCF

MOCHOVCE NPP



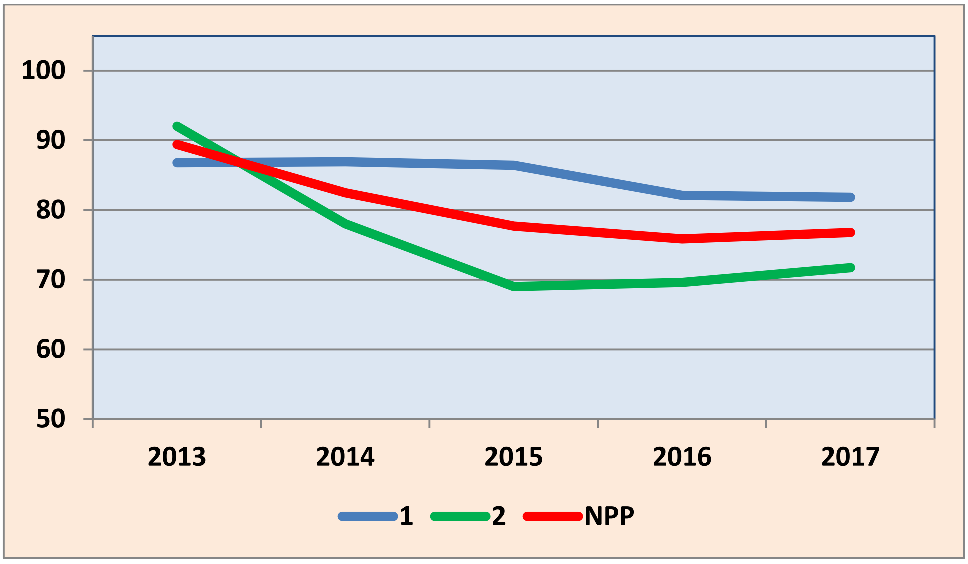
Unit	Year	Main contributors
1	2013	-
	2014	-
	2015	-
	2016	-
	2017	UCF
2	2013	-
	2014	UCF
	2015	UCF
	2016	-
	2017	-

BOHUNICE NPP



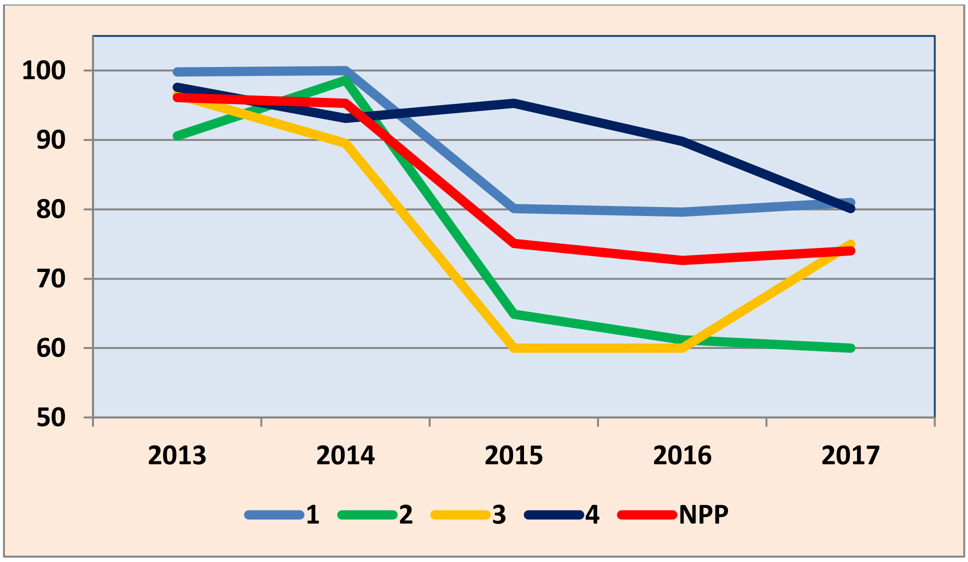
Unit	Year	Main contributors
3	2013	-
	2014	-
	2015	UCF
	2016	ISA2, UCF
	2017	ISA2, UCF
4	2013	-
	2014	-
	2015	-
	2016	ISA2, UCF
	2017	ISA2, UCF

TEMELIN NPP



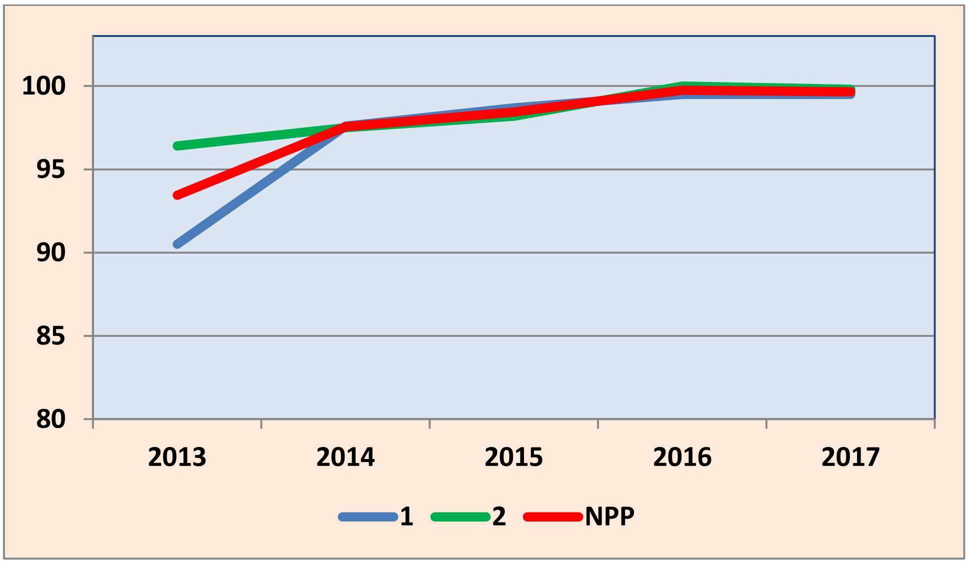
Unit	Year	Main contributors
1	2013	FLR, FRI, UCF
	2014	UCF
	2015	FLR, ISA2, UCF
	2016	FLR, ISA2, UCF
	2017	FRI, UCF
2	2013	FLR, UCF
	2014	FLR, FRI, UCF
	2015	FLR, FRI, ISA2, UCF
	2016	FLR, ISA2, UCF
	2017	FLR, FRI, UCF

DUKOVANY NPP



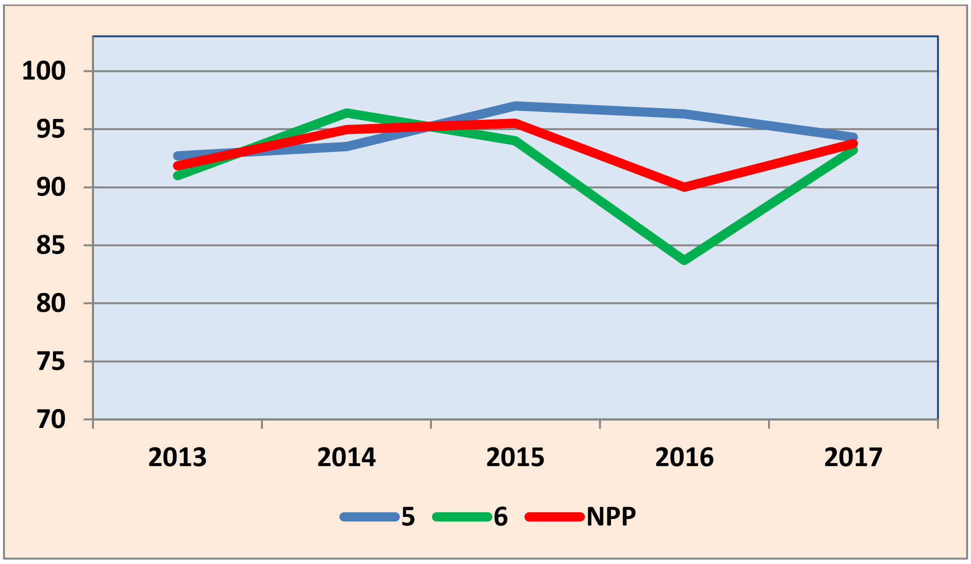
Unit	Year	Main contributors
1	2013	UCF
	2014	-
	2015	SP1, UCF
	2016	SP1, UCF
	2017	SP1, UCF
2	2013	UCF
	2014	UCF
	2015	FLR, SP1, UCF
	2016	FLR, SP1, UCF
	2017	FLR, SP1, UCF
3	2013	UCF
	2014	FLR, UCF
	2015	FLR, SP1, UCF
	2016	FLR, SP1, UCF
	2017	SP1, UCF
4	2013	UCF
	2014	FLR, UCF
	2015	FLR
	2016	FLR, UCF
	2017	FLR, UCF

LOVIISA NPP



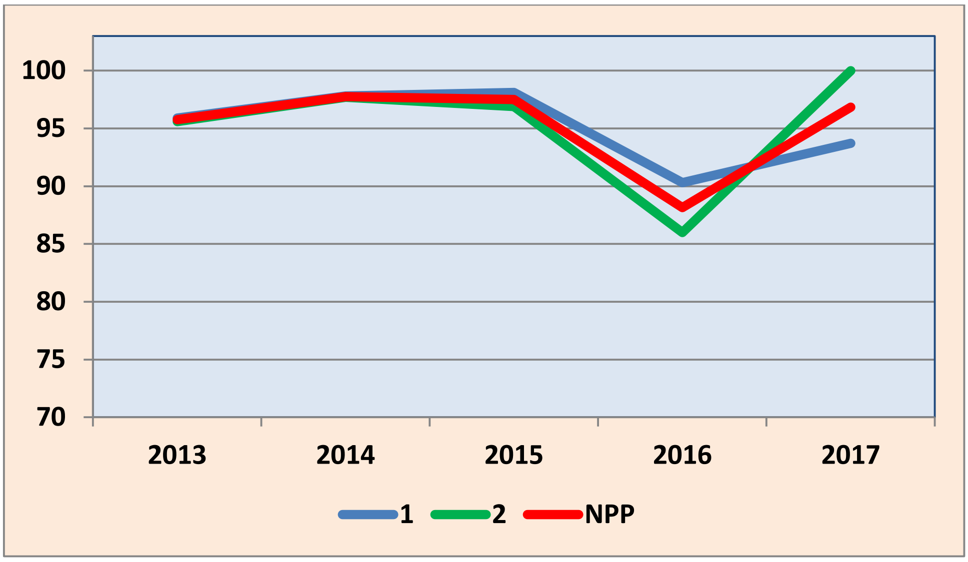
Unit	Year	Main contributors
1	2013	CRE, ISA2, UCF
	2014	ISA2
	2015	ISA2
	2016	UCF
	2017	ISA2, UCF
2	2013	FLR, ISA2
	2014	ISA2, UCF
	2015	FLR, ISA2, UCF
	2016	-
	2017	ISA2,

KOZLODUY NPP



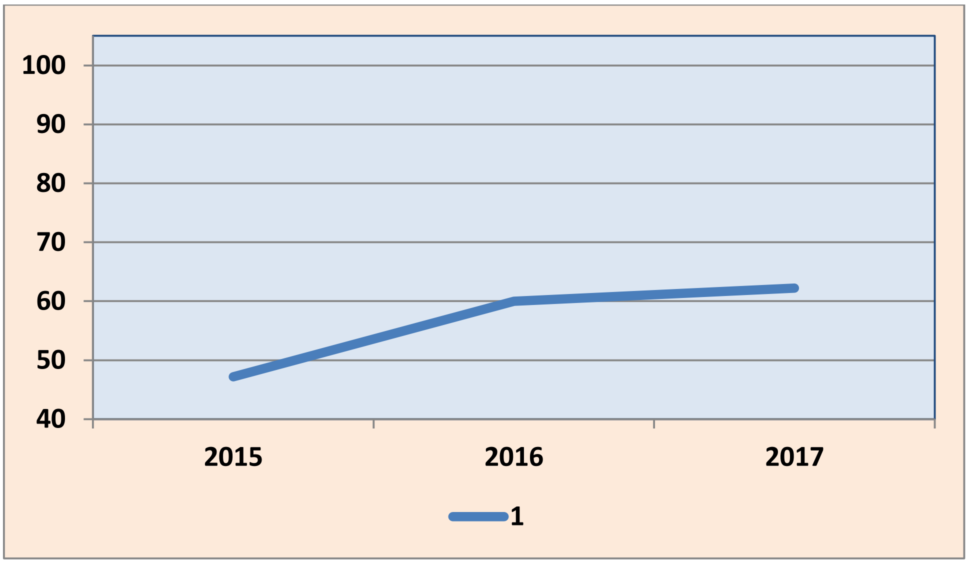
Unit	Year	Main contributors
5	2013	CPI, FLR, UCF
	2014	FLR, UCF
	2015	CPI, UCF
	2016	CPI, UCF
	2017	CPI, UCF
6	2013	FLR, UA7, UCF
	2014	UCF
	2015	UCF
	2016	UCF
	2017	CRE, UCF

TIANWAN NPP



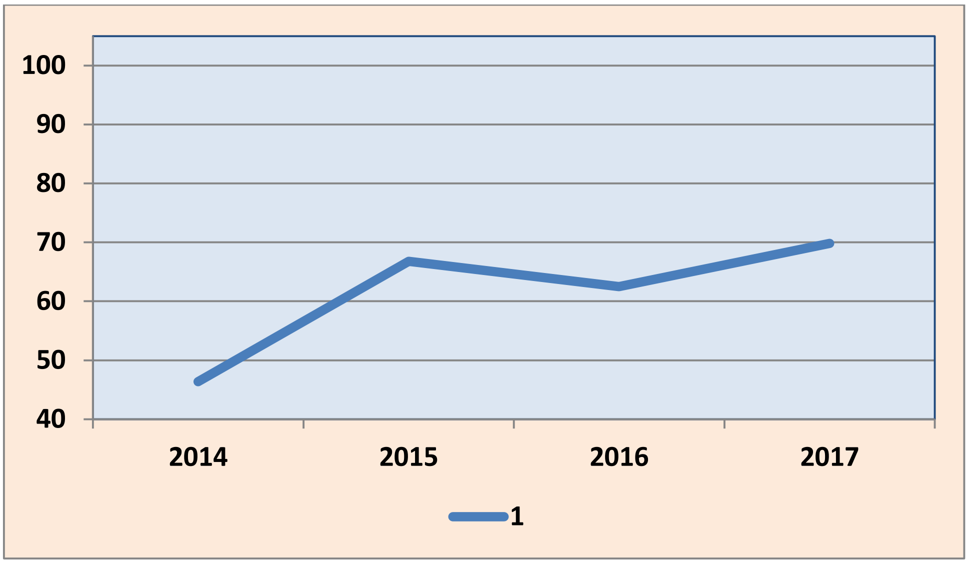
Unit	Year	Main contributors
1	2013	UCF
	2014	UCF
	2015	UCF
	2016	FLR, FRI, UCF
	2017	UCF
2	2013	UCF
	2014	UCF
	2015	UCF
	2016	UA7
	2017	-

KUDANKULAM NPP



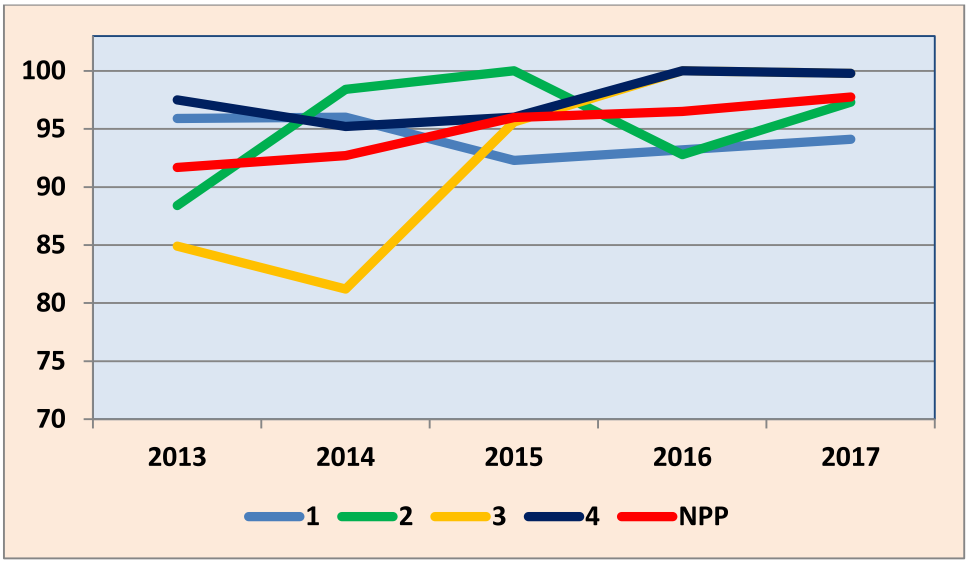
Unit	Year	Main contributors
1	2016	FLR, FRI, UA7, UCF
	2017	FLR, SP1, UA7, UCF

BUSHEHR NPP



Unit	Year	Main contributors
1	2014	FLR, ISA2, UA7, UCF
	2015	FLR, UA7, UCF
	2016	FLR, UA7, UCF
	2017	FLR, UA7, UCF

PAKS NPP



Unit	Year	Main contributors
1	2013	CPI, ISA2, UCF
	2014	FRI, UCF
	2015	CRE, UCF
	2016	UCF
	2017	CRE, FLR, ISA2, UCF
2	2013	CRE, CPI, FLR, ISA2, UCF
	2014	FLR, UCF
	2015	-
	2016	-
	2017	ISA2, UCF
3	2013	CRE, ISA2, UCF
	2014	CRE, CPI, UCF
	2015	CPI, UCF
	2016	UCF
	2017	ISA2
4	2013	CPI, FLR, ISA2, UCF
	2014	UCF
	2015	UCF
	2016	-
	2017	ISA2

4. WANO Performance Indicators

4.1 Analysis of Energy Generation PIs

This subsection covers the output production data over the MC plants, provides analytical data on WANO PIs, which enable monitoring of output production process. The data gathered throughout the 10 years' period (2008 - 2017) was analysed.

The PIs system covers as well energy generation process at NPPs. Certain PIs can not only reflect an NPP's capability of power production, but as well allow to consider electricity, which could have been produced, but for a variety of reasons was to be considered as generation loss.

The "energy generation" PIs group includes as follows:

- UCF – Unit Capability Factor
- UCLF – Unit Capability Loss Factor
- FLR – Forced Loss Rate
- GRLF – Grid Loss Capability Factor
- UA7 – Unplanned Total Automatic Reactor Scrams per 7000 Hours Critical
- US7 – Unplanned Total Manual Reactor Scrams per 7000 Hours Critical

It is worth noting that this PIs group is the largest. Its importance is additionally stressed by two PIs (FLR and US7) out of five, which are key indicators to the world nuclear community.

Nuclear power plants were designed and are now operated to serve their chief purpose – safe electricity production. There was a time when nuclear enabled NPPs to produce large quantities of electricity at a relatively low cost. As of the end of 2017 the WANO PIs database contained data of 74 power units and 5 Atomflot nuclear vessels to be processed. Installed capacity of NPPs power units was **58.913** GWt power. **Fig.10** presents the installed capacity trends within WANO MC over the last 10 years.

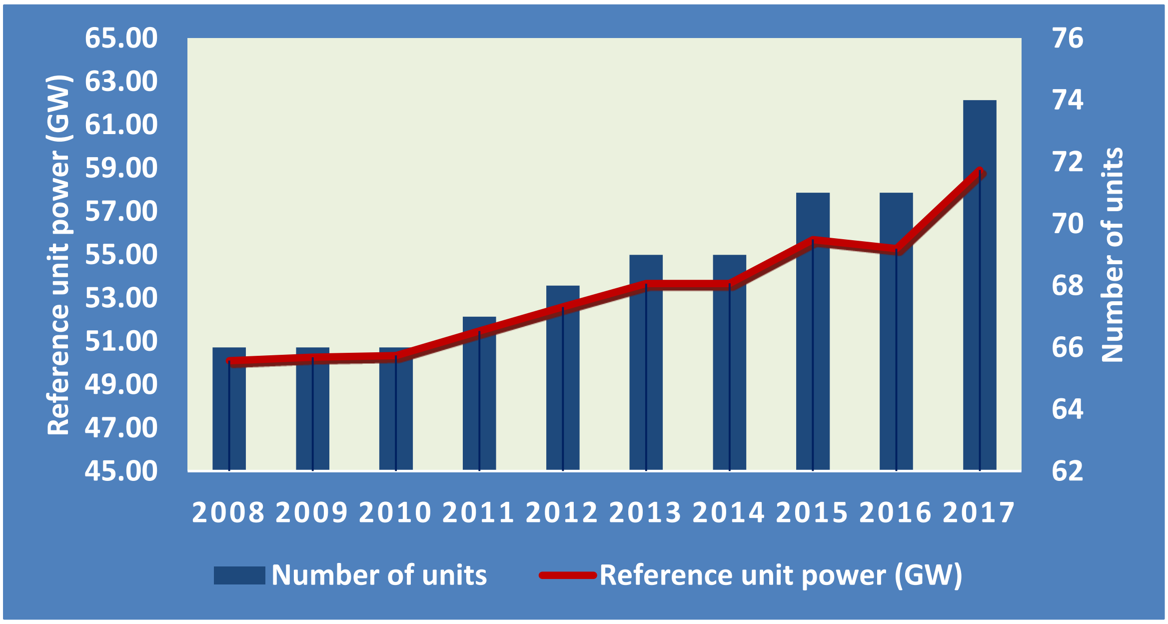


Fig.10

Over the 10 years' period 8 new power units have been commissioned and 1 power unit has been decommissioned. **Table 6** presents their entrance into the DES database.

Table 6

Year, quarter	NPP	Unit No	Design capacity, MWt
2011 (c 2011Q1)	Rostov	2	1000
2012 (c 2012Q4)	Kalinin	4	1000
2013 (c 2013Q4)	Bushehr	1	1000
2015 (c 2015Q4)	Rostov	3	1000
2015 (c 2015Q1)	Kudankulam	1	1000
2017 (c 2017Q1)	Novovoronezh	3	417
2017 (c 2017Q1)	Beloyarsk	4	885
2017 (c 2017Q2)	Kudankulam	2	1000
2017 (c 2017Q2)	Novovoronezh	2-1	1180,3

At that, total installed capacity has increased by **8,81 GWt** representing a 17,5% increase as compared with the data of 2008. It is as well worth noting that it was not only commissioning of new generating capacities, what contributed to enhanced total power production of Moscow Centre NPPs, but also the comprehensive works on equipment modernization and on increasing the power units' capacities. **Table 7** presents data of power units included into the programme for increase of their power generating capacities.

Table 7

NPP	Unit No	Design capacity, MWt	
		2008Q1	2017Q4
Bohunice	3	441	505
	4	441	505
Dukovany	1	456	500
	2	440	500
	3	456	500
	4	456	500
Loviisa	1	510	531
	2	510	526

NPP	Unit No	Design capacity, MWt	
		2008Q1	2017Q4
Mochovce	1	440	470
	2	440	470
Paks	1	500	500
	2	470	500
	3	470	500
	4	500	500
Temelin	1	1013	1080
	2	1013	1080
Tianwan	1	1000	1060
	2	1000	1060
Total power generation, MWt:		10556	11287

Volumes of energy generated by NPPs of Moscow Centre has enlarged by 731 MWt during 10 years representing **1,45%** of NPPs installed capacity in 2008. 4 NPPs, whose data is stored in DES system since 1990, have increased their electrical power production upto **1122,8 MWt** due to increase of their energy production capacity. This data is presented in **Table 8**.

NPP	Unit No	Design capacity, MWt	
		1990Q1	2017Q4
Bohunice	3	435,7	505
	4	436	505
Dukovany	1	432	500
	2	438	500
	3	451,7	500
	4	447,7	500
Loviisa	1	465	531
	2	465	526
Paks	1	439,7	500
	2	449,7	500
	3	459,7	500
	4	459,7	500
Total energy generation, MWt:		4944,2	6067

DES system data allows to monitor parameters of energy generation among MC NPPs. **Fig. 11** presents energy generation data in graphs. The red curve on this graph shows gross energy generation within MC including installed capacity of power units. This means, this curve shows volumes of energy, which could have been produced during 10 years, if the power units operated at full capacity throughout this period. Next curve shows net power generation within MC. Net here stands for power volume, produced by NPPs taking into account all kinds of losses (to be specified below) and dispatch restrictions, which are not under authority of plant management. And the last curve, which is the difference between gross and net energy, presents the energy losses or volumes of energy which was not generated due to some reasons. It must be mentioned that despite good indicators showing raising volumes of energy generation across MC, the loss rates raise also. During the last 10 years, losses volumes increased by **15%** in comparison with 2008 and amount 97 TWt/h as of the end of 2017. Analysis of energy losses graph was performed to reveal certain features. In the period of 2008 – 2012 the indicators value was rather stable with light positive trend of decrease by **2,7%** (amounts **2,3 TWt/h**) while there was a constant increase of net energy generation observed. In 2013 there was a sharp increase of generation losses by **11%** (amount about **8,9 TWt/h**), while the net energy generation volumes remained stable with just slight decrease (change was in the period of 2012-2013 was within **0,25%** or **0.93 TWt/h**).

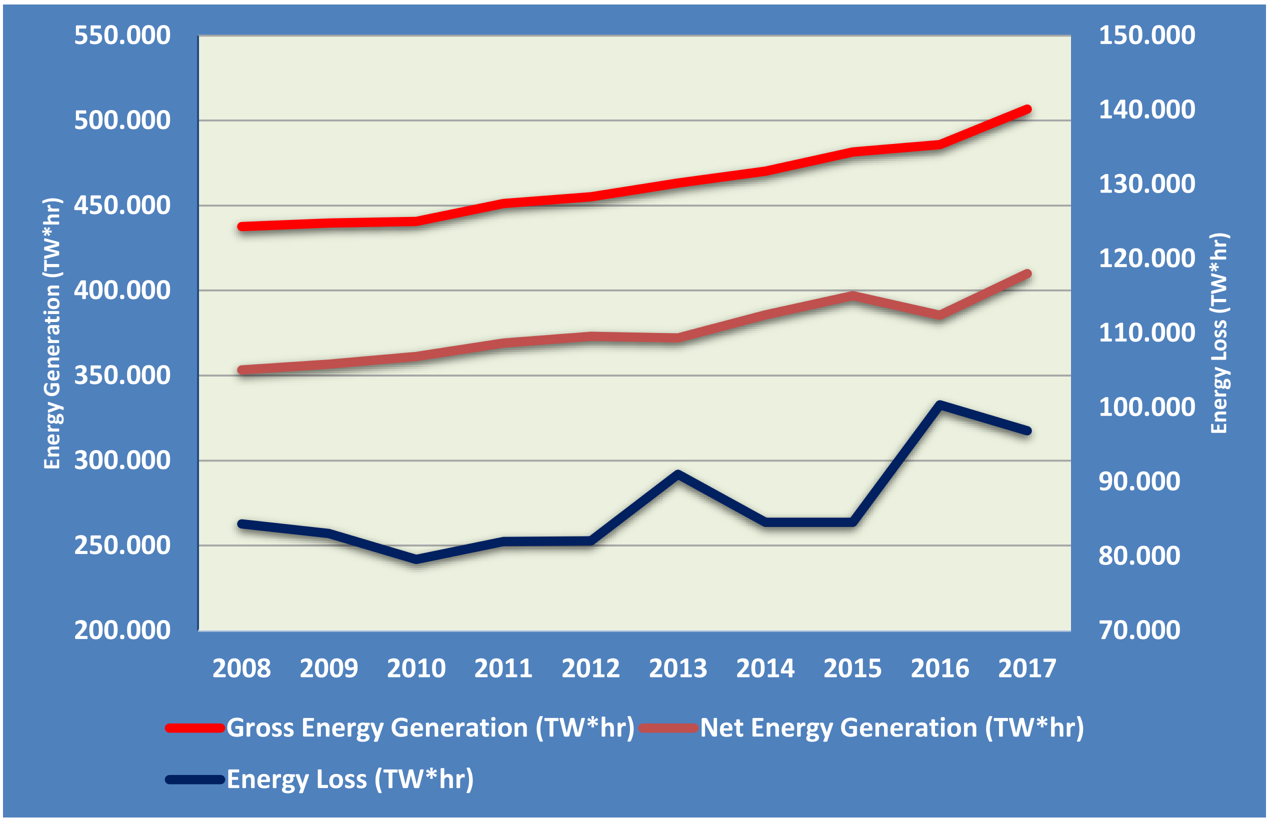


Fig.11

Next significant spike in energy generation losses observed has started in 2015. In 2016 it amounted to 19 percent (or approximately **15,8 TWt/h**). By the end of 2017 the trend starts to slightly lower, nevertheless the values remain significant to require special attention of the operating organizations.

Fig. 12 presents a more detailed information on energy generation losses trends including data considered within the WANO PI Programme. Such as the four types of energy generation losses: planned, unplanned, forced losses, unplanned downtimes in outages and unplanned power generation losses due to loss of grid.

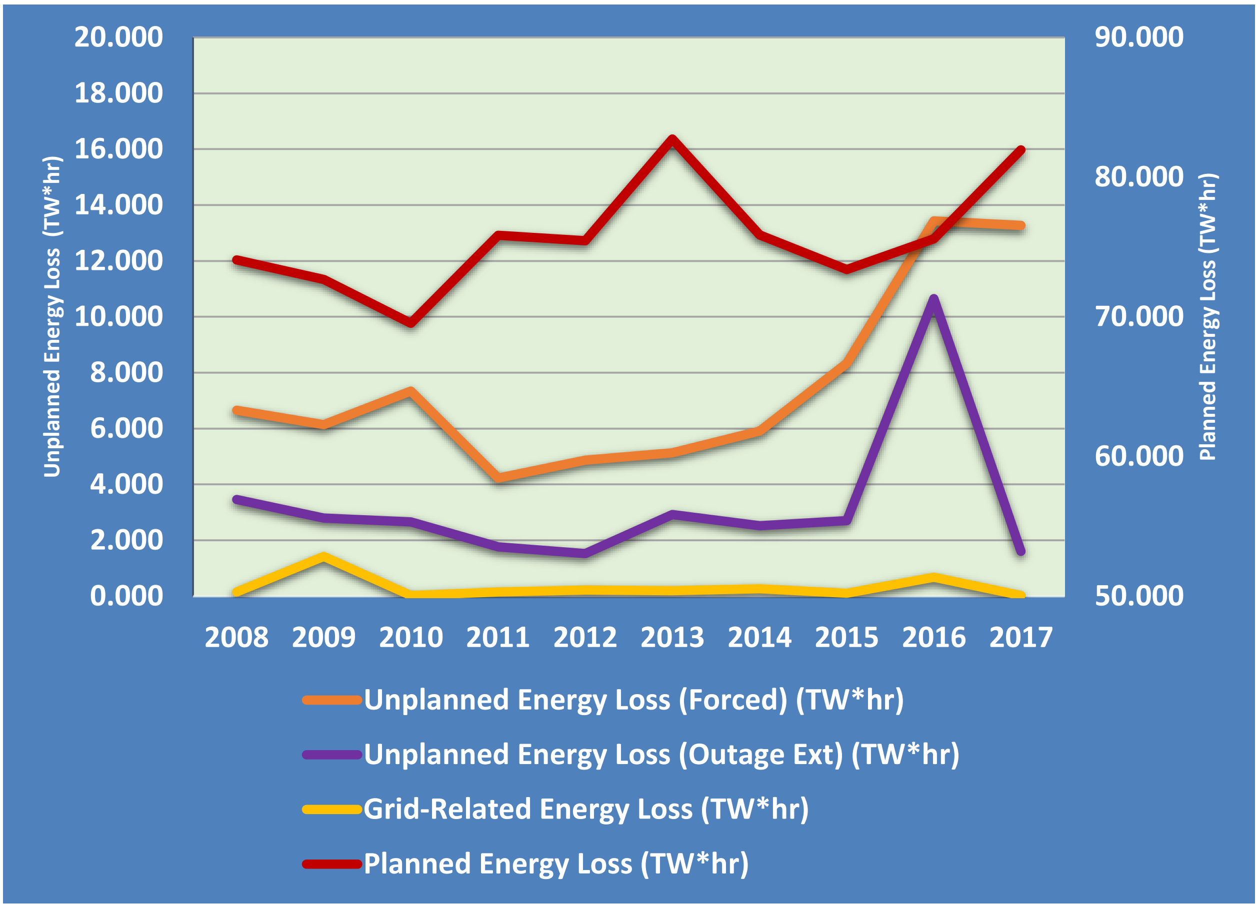


Fig. 12

Fig.3 and **table 9** present a histogram (a ratio of parameters) and data in figures accordingly, which demonstrate how the energy generation losses types percentage is distributed in 10 years' period. Total energy generation losses in figures amounted **84,33** TWt/h (2008) and **96,87** TWt/h (2017).

Energy generation losses due to loss of grid make the smallest contribution to the total. This PI value remains stable over MC and amounts approximately from 0,2% in 2008 to 0,03% in 2017. The main contribution to energy generation losses is done by electrical equipment failures – main unit transformers, which provide the "glue" to hold a power unit and grid together.

Trends of ratio between values of the rest three PIs (planned losses, forced losses and downtimes in outage) are of greater interest. Values of energy generation PIs correspond to the world best practice when NPPs experience no cases of downtime in outages, the forced loss rate is minimal, and planned losses rate is maximal. As we can see from **fig. 13** and **table 9,** the planned energy generation losses at NPPs of Moscow Centre are the largest part and are within 75 – 92% of total losses. As well, during the last 10 years a negative trend was observed, planned losses rate has decreased and in 2017 was approximately 85%, in 2016 – it was 75% of total energy generation losses. The reason of this negative trend was forced loss rate increase, which was 13,7 percent of total as of the end of 2017, having almost doubled from 2008.

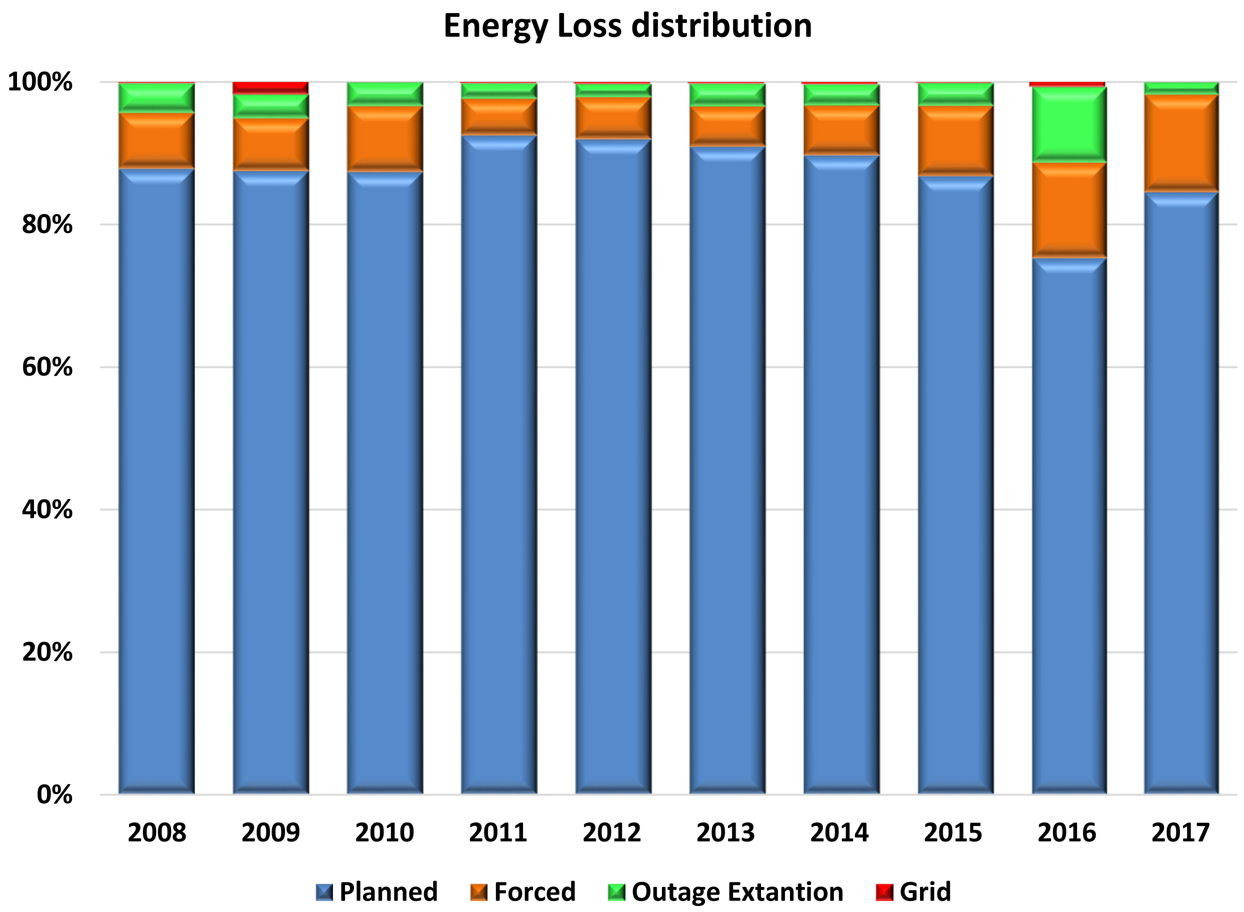


Fig. 13

Table 9

Types of energy losses	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Planned losses, %	87.83	87.53	87.40	92.50	92	90.93	89.71	86.81	75.33	84.6
Forced losses, %	7.89	7.39	9.22	5.15	5.93	5.65	6.99	9.87	13.39	13.7
Outage extension (downtime), %	4.10	3.36	3.35	2.16	1.86	3.21	2.98	3.19	10.62	1.7
Loss of the grid, %	0.20	1.72	0.03	0.19	0.27	0.21	0.32	0.13	0.67	0.03

The most optimal operating period was observed in 2011. During this period the forced loss rate was minimal – 5,15 percent, and the planned losses were at their maximal point – 92,5 percent.

At the same time the downtime in outages value has been improving throughout 10 years and decreased from 4,1percent to 1,7 percent. Nevertheless, attention must be paid to the period from 2013 to 2016, when there was a spike in PI values due large scopes of work on power units' life extension.

Let us now consider the results of energy generation of Moscow Centre NPPs and what place does MC take among other regional centres. Figures **14 ÷ 17** present trends of UCF and FLR indicators among RCs, which are main indicators to determine energy generation. It is worth saying that UCF also determines a possibility for improvement of energy generation efficiency, and FLR represents the rate of energy losses, which occurred while the energy was not generated unplanned or forced, due to equipment failures.

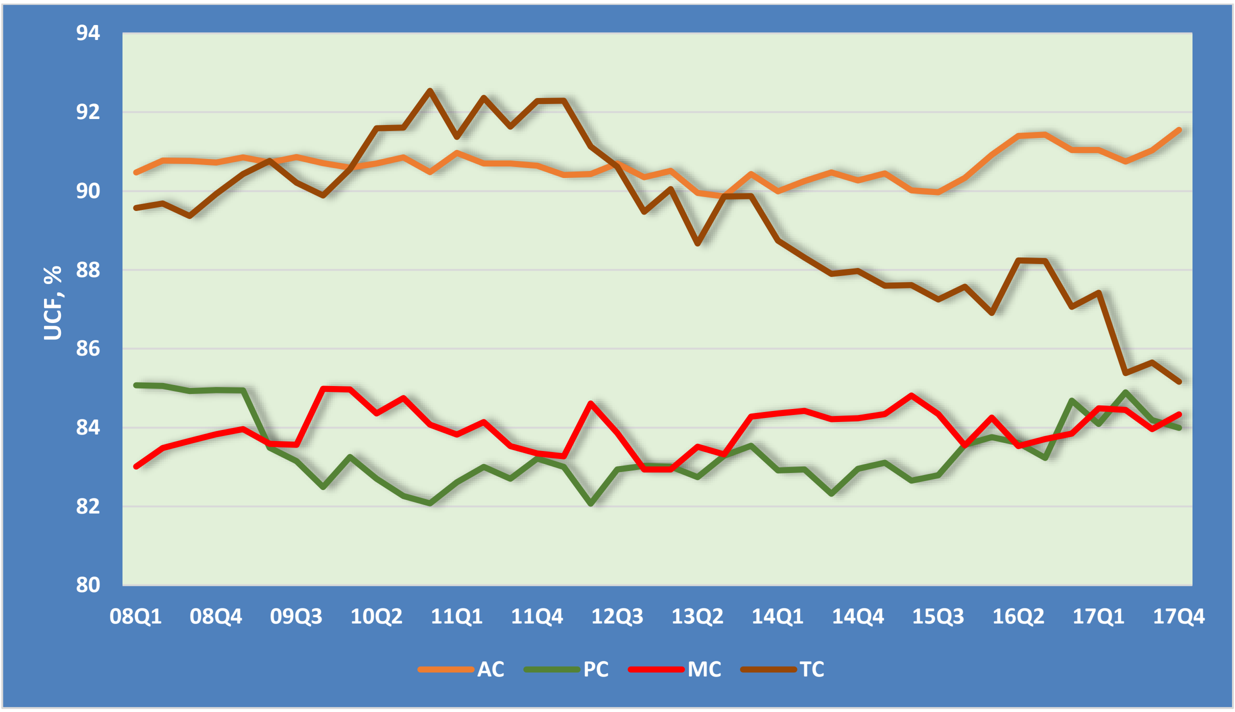


Fig. 14 UCF median values trend chart by Regional Centres.

UCF values testify for substantial opportunities to improve energy generation of MC NPPs. As it becomes clear from **fig. 14** the median values of our regional centre are close to 85% and thus take third place among other RCs, slightly outpacing PC just by a little more than 1%. The opportunities to further improve values of this PI are in place, but they are not many and mostly limited to approaches towards organization of maintenance at MC NPPs.

At the same time, **fig. 15** contains charts presenting difference between the worst and the best quartile values by RCs. AC occupies here the first place, same as in the **UCF** median values chart. But relatively close position of quartile values (of the best and the worst quartile) is as well rather typical for MC NPP and proves to good load of power units in terms of energy generation.

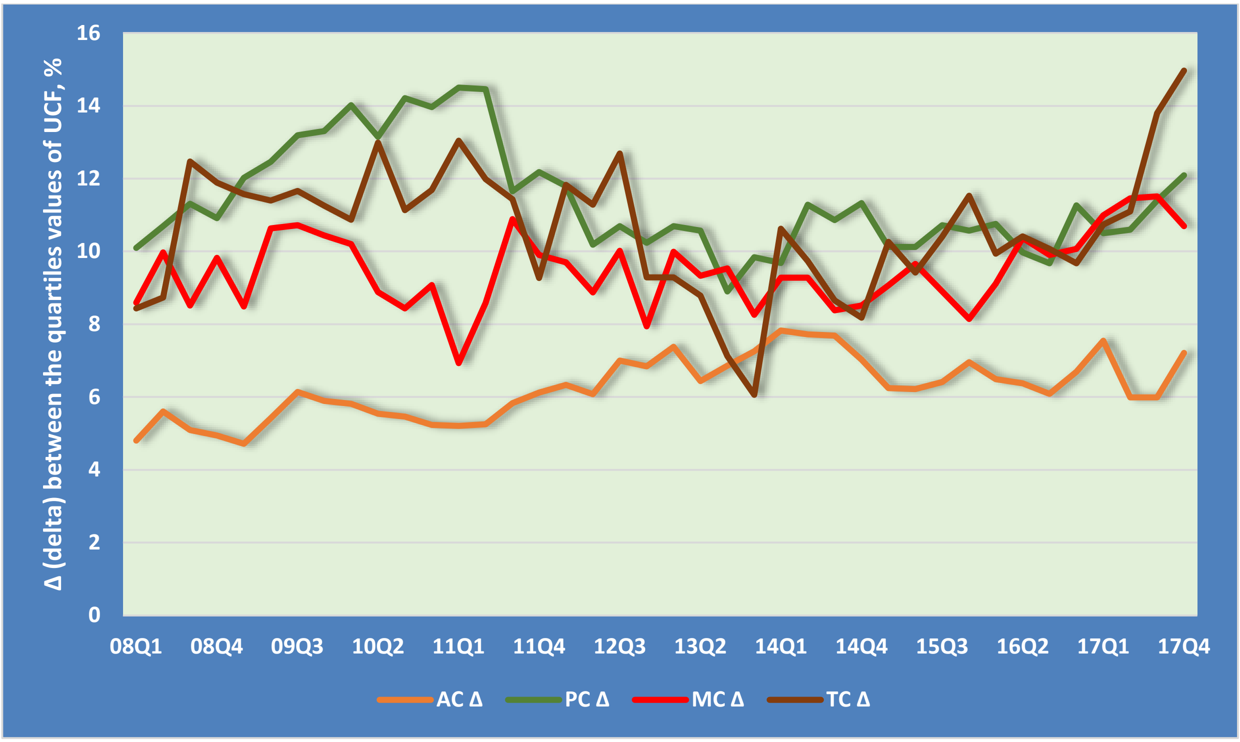


Fig. 15 Difference (delta Δ) between the best and the worst quartile threshold values of UCF among regional centres.

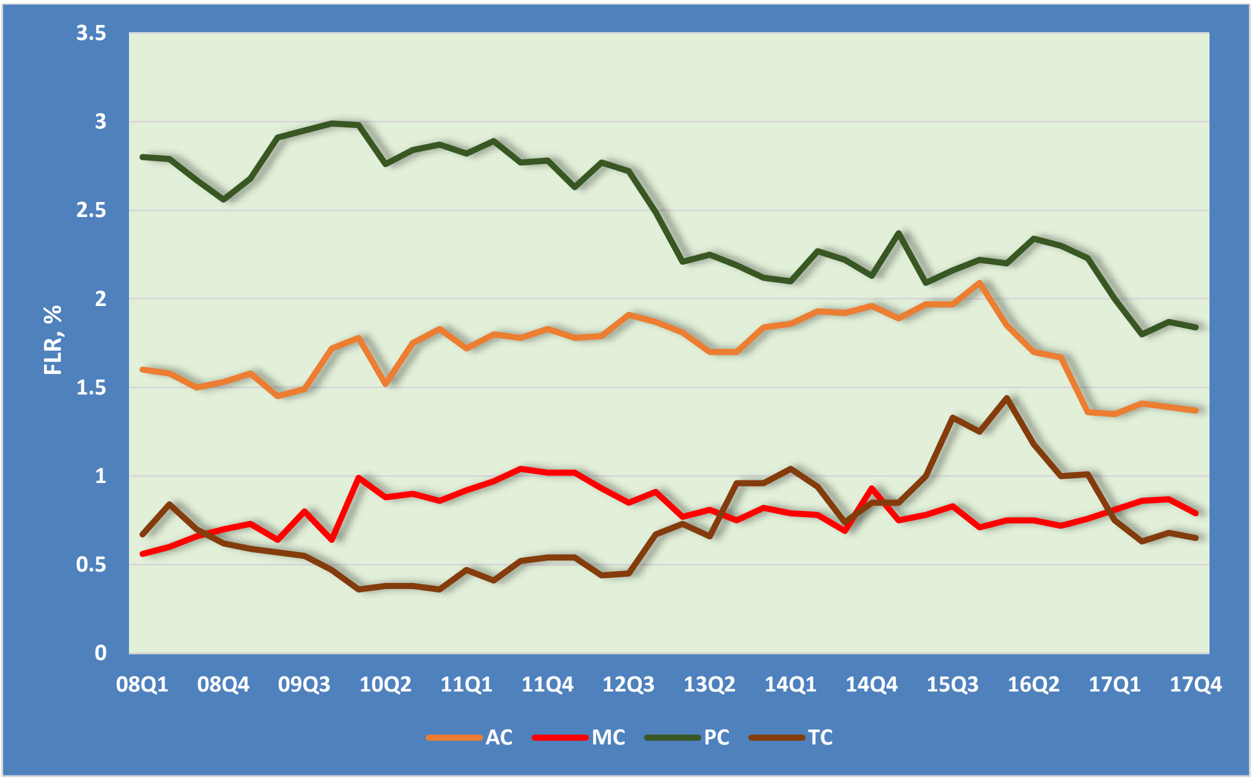


Fig. 16 FLR median values by regional centres

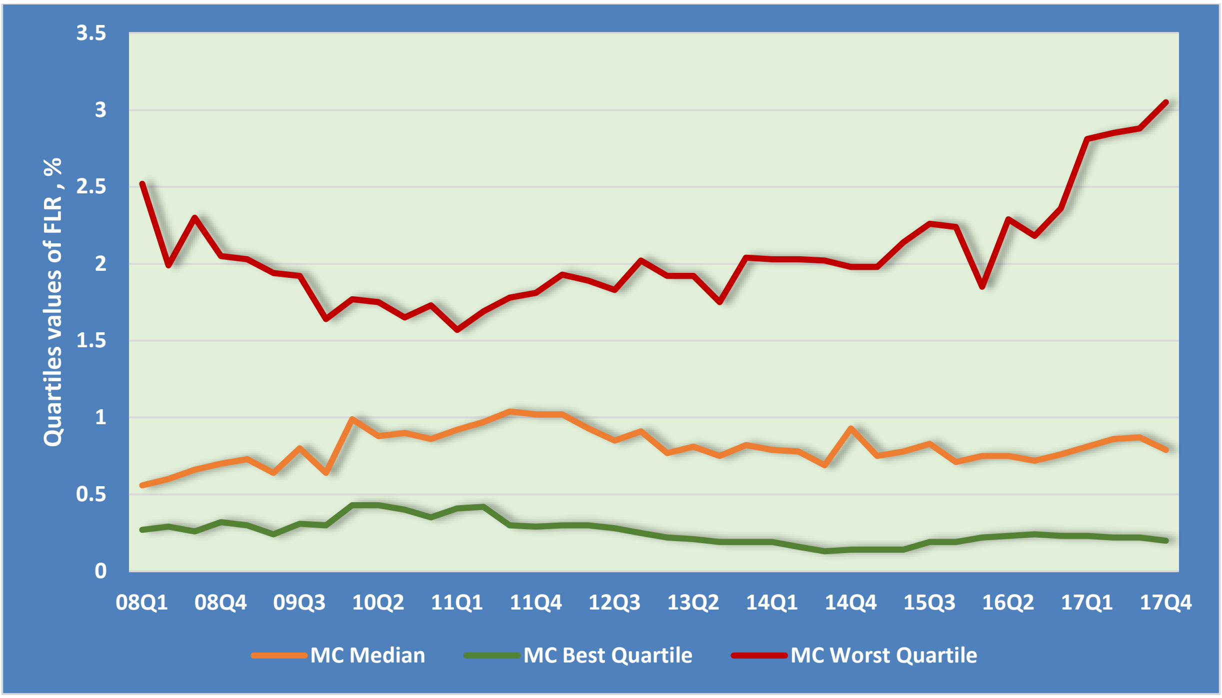


Fig.17 Quartiles values trends of **FLR** across MC

With regards to equipment failures (**fig. 16**) – they occur and it is clearly seen on the chart. Nevertheless, the rate of generation losses occurred due to equipment failures is typically low within MC. By the end of 2017 median value was 0,8% of total generation what placed MC the 2nd after TC. If consider MC data alone and in details (**fig. 17**), it becomes obvious, that median value has increased, though slightly (negative sign) and the worst quartile threshold value has substantially risen (as of the end of 2017 it was 3,05%). Shift of the worst quartile threshold value is explained by conditions of operation of 6 MC power units, which have the FLR value within 8 to 18%.

Sampling of PI values over MC NPPs was carried out to enable further analysis of **FLR** and **UCF** data throughout the last 10 years. The purpose of such analysis was grouping of power units around time period they spent in a relevant quartile (the upper or the lower). Analysis conditions are as follows:

- Consider the fact of presence of a power unit/NPP in any quartile during a relevant year;
- Calculation cycle – is 36 months;
- Only the data of the end of the relevant year (4th quartile) undergone consideration;
- Only the best quartile data of UCF indicator undergone analysis;
- If all the power units of an NPP were/were not in a relevant quartile, only the name of NPP is given, numbers of power units not specified.

Results of analysis are presented in **tables 10** (**FLR** data) and **11** (**UCF** data).

Table 10

Not in quartile	For 3 and more years	For 5 and more years	For 10 years	Comment
Worst quartile				
Kalinin 2	Kursk 4	Kursk 3	Kursk 1	Rovno 4 – 1 time in 2008; Bohunice 4 – 1 time in 2008; Tianwan 1 – 1 time in 2009; Kursk 2 – 1 time in 2017; Kalinin 2 – during 9 years; Kudankulam 1 – during 2 years since commissioning
Leningrad 2	Kalinin 4	Kalinin 1	Novovoronezh 5	
Balakovo 1	Leningrad 3	Kalinin 3		
Balakovo 3	Novovoronezh 4	Leningrad 1		
Dukovany 1	Balakovo 2	Leningrad 4		
Khmelnitski 1	Smolensk 3	Smolensk 1		
Tianwan 2	Bushehr 1	Smolensk 2		
Kola 2	Temelin 1	Rovno 3		
Bilibino NPP	Temelin 2	South- Ukraine 2		
Zaporozhye NPP	South-Ukraine 1	Khmelnitski 2		
Paks NPP	South- Ukraine 3	Armenian 2		
Kozloduy NPP	Dukovany 2			
Mochovce NPP	Dukovany 3			
Loviisa NPP	Beloyarsk 3			
	Kola 4			
Best quartile				
Kola 3	Balakovo 3	Bilibino 1	Bilibino 3	
Paks 2	Khmelnitski 1	Bilibino 2		
Dukovany 4	Khmelnitski 2	Bilibino 4		
South- Ukraine 2	Rovno 2	Balakovo 1		
South- Ukraine 3	Rovno 3	Balakovo 4		
Novovoronezh 5	Kola 2	Rovno 1		
Beloyarsk 3	Kola 4	Rovno 4		
Armenian 2	Paks 1	Kola 1		
Bushehr 1	Loviisa 2	Paks 4		
Smolensk NPP	Zaporozhye 4	Dukovany 1		
Temelin NPP	South- Ukraine 1	Loviisa 1		
Kudankulam NPP	Kozloduy 5	Zaporozhye 5		
Kalinin NPP	Kozloduy 6	Zaporozhye 6		
Leningrad NPP	Tianwan 1	Tianwan 2		
Kursk NPP		Bohunice 3		
Rostov NPP		Bohunice 4		

Table 11

Not in quartile	For 3 and more years	For 5 and more years	During 10 years
Best quartile			
Kola 3,4	Balakovo 2	Paks 2	Mochovce 1
Dukovany 2	Tianwan 2	Paks 3	Mochovce 2
Novovoronezh 5	Leningrad 2	Paks 4	Loviisa 1
Kalinin 1,3,4	Kozloduy 6	Balakovo 1	Loviisa 2
Rovno 2,3,4	Dukovany 1	Balakovo 3	
Khmelnitski NPP	Dukovany 3	Balakovo 4	
Beloyarsk NPP	Dukovany 4	Rostov 1	
South-Ukraine NPP	Bilibino 2	Rostov 2	
Zaporozhye NPP		Kozloduy 5	
Kudankulam NPP		Bohunice 3	
Bushehr NPP		Bohunice 4	
Temelin NPP			
Armenian NPP			

Results of analysis:

Forced Loss Rate (FLR)

- Bilibino NPP demonstrated the best performance in terms of this PI: none of the power units was ever in worst quartile (along the analyzed period), but all power units belonged to the best quartile during 5 years, and unit 3 was the only one among the power units of MC to belong to the best quartile during 10 years. These conditions can be explained by low power level of the units, and therefore low load for NPP equipment.

- Good performance in terms of the considered PI was demonstrated as well by NPPs of East-European part of MC, in particular Loviisa NPP, Kozloduy NPP, Paks NPP, and also by Tianwan NPP. None of their power units were in the worst quartile during 10 years and majority of them belonged to the best quartile at least during 3-5 years.

- Rather good results of PI values analysis were revealed at the following group of NPPs: Bohunice, Balakovo, Zaporozhye, Kola, Khmelnitsky. Some of their power units made minimal contribution to the worst quartile, at that most of their power units were in the best quartile.

- A group of NPPs has satisfactory values of PI, which determines forced energy losses due to equipment failures, as follows: Temelin NPP, Beloyarsk NPP, South-Ukraine NPP, Rostov NPP. Further actions are required to improve safety and performance level.

- A group of NPPs in need of increased attention to improve operational safety would include all NPPs with LWGRs and some of NPPs with VVERs, they are: Kalinin NPP, Bushehr NPP, Armenian NPP, Novovoronezh NPP, Kudankulam NPP.

Unit Capability Factor (UCF)

- The best results were demonstrated by Loviisa NPP and Mochovce NPP: power units belong to the best quartile along the last 10 years, and it is also remarkable, that the 2nd Slovak NPP – Bohunice NPP as well demonstrates best performance analysis results (its unit No 3 is in the best quartile since 2010, and unit No 4 – since 2011).

- Results UCF values analysis allow to reveal a relation between the dissemination of power units against the criteria of the best and worst quartiles and the reactor facility type, which is VVER-440. Modified designs of this reactor facility are likely to demonstrate stable high performance in power generation at the East-European NPP of MC. Aside of the named above good performance was demonstrated as well by Paks NPP (2,3,4) and Dukovany NPP (1,3,4). However, on the other hand a number of similar power units operated by the Ukrainian (Rovno MPP) and Russia (Kola NPP) utilities have either been once in the best quartile or (Rovno 1, Kola 1,2) or never at all (Rovno 2, Kola 3,4).

- Some of the NPPs operating VVER-1000 reactor are worth noting, such as Balakovo NPP for it is a stably good performing plant (all of its power units are in the best quartile for more than 3 years), Rostov NPP and Kozloduy NPP. Outstanding is progress at Tianwan NPP. A complex of activities aimed at PI improvement was carried out at this NPP, and since 2014 power unit No 2 never leaves the best quarter, and power unit No 1 is in the best quartile for 2 years already.

- Good performance results are demonstrated by some power units of Russian NPPs, although their approach is not systematic, while they cannot come to stable results (years in best quartile is given in claims): Smolensk 2 (1) and 3 (2), Kursk 1 and 3 (1 year each), Leningrad 3 (2), Kalinin2 (2), Kola 1 and 2 (1 year each), Novovoronezh 4 (1).

- NPPs must be placed, which have power units never got into the best quartile, as follows: Khmelnitski, Beloyarsk, South-Ukraine, Zaporozhye, Temelin, Bushehr, Armenian, Kudankulam NPPs.

Cases of reactor scram actuation – is another parameter determining safe power units' operation. WANO PI system has two indicators **UA7** and **US7** intended to monitor scram frequency. The purpose of the first one is to monitor automatic scrams, and the scope of the second one includes scrams actuated manually. Regarding scram actuation, the situation within MC is rather secure. **Fig. 18** presents comparison of **UA7** values of all regional centres. **Fig. 19** presents same comparison of **US7** values.

Figures describing the scram actuation frequency at NPPs of MC are presented in **table 12.**

Figures 18 and **19** and **table 12** show that cases of scram actuation are relatively rare in comparison with other regional centres. Scram actuation rate in 10 years' period tends to lower and counts on average 0,26 scrams per 1 unit, what makes 1 scram per unit in a 4-year period.

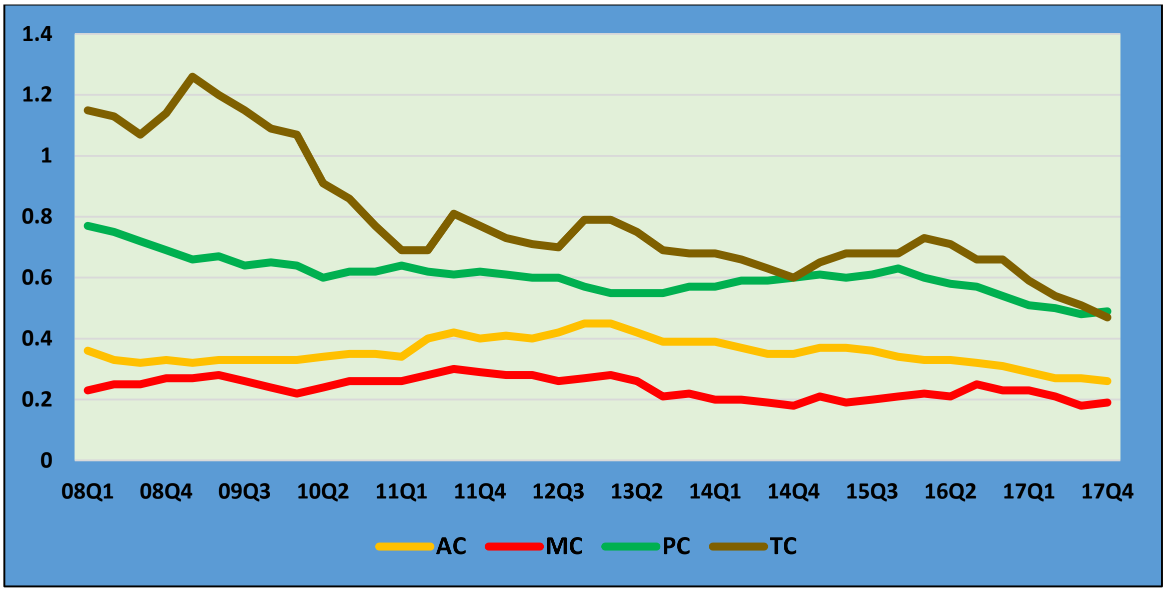


Fig.18 Change of **UA7** median values by regional centres.

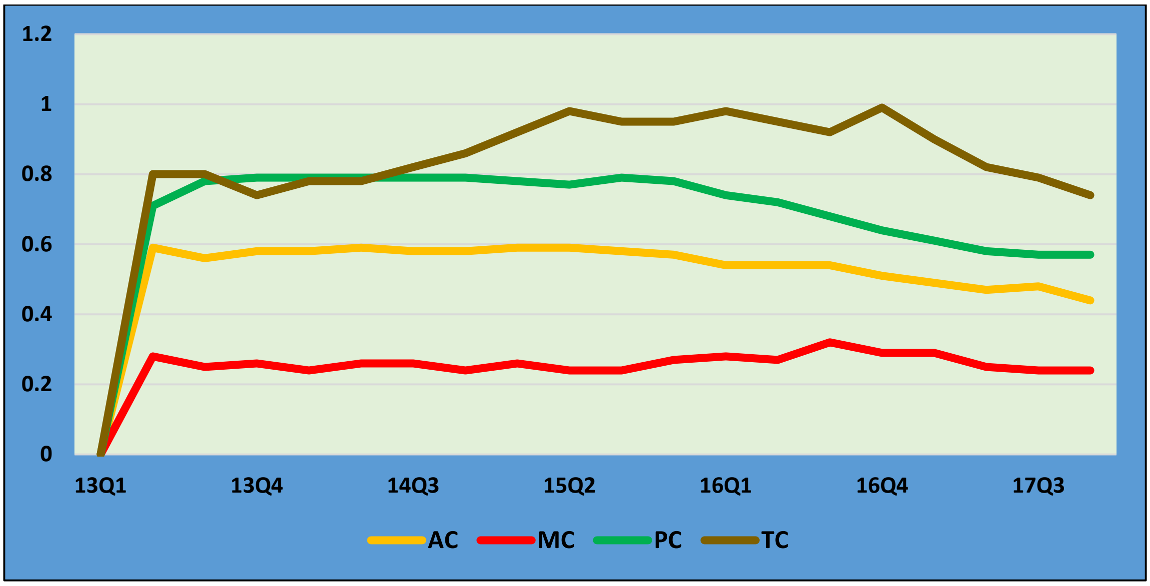


Fig. 19 Change of US7 median values by regional centres.

Scram	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Automatically actuated	16	15	22	19	14	15	13	15	17	7+2*
Manually actuated	0	0	0	0	7	3	3	7	3	3
Units in operation	66	66	66	67	68	69	69	71	71	73+5*
Total scrams divided by MC units number	0,24	0,23	0,33	0,28	0,31	0,26	0,23	0,31	0,28	0,15
* taking into account the units of FSUE Atomflot										

4.2 WANO Performance Indicators Review

This subsection defines all WANO PIs for the MC stations and provides data on median values history and worst quartile threshold values across MC throughout five years' period. The data has been selected following a 36-monthes calculation cycle except for **FRI**, which data is to be selected and calculated following a 3-months calculation cycle. Average values are used to monitor scrams (**UA7** and **US7**) instead of median values.

Statistical approach being a principle of "WANO PI" Programme promises that there will always exist the power units referred to worst or best quartile. It can't be changed. It is important to track changes of quartile values limits.

This subsection considers 3-year period data, beginning with the last quarter of 2017 and back, to identify power units in need of additional attention and support in their striving towards performance improvement. Power units are shown, which keep their position on quartile data chart in "lower" quartile and "lower than median" for a longer period (50% and more time of the considered time period).

4.3 UCF – Unit Capability Factor

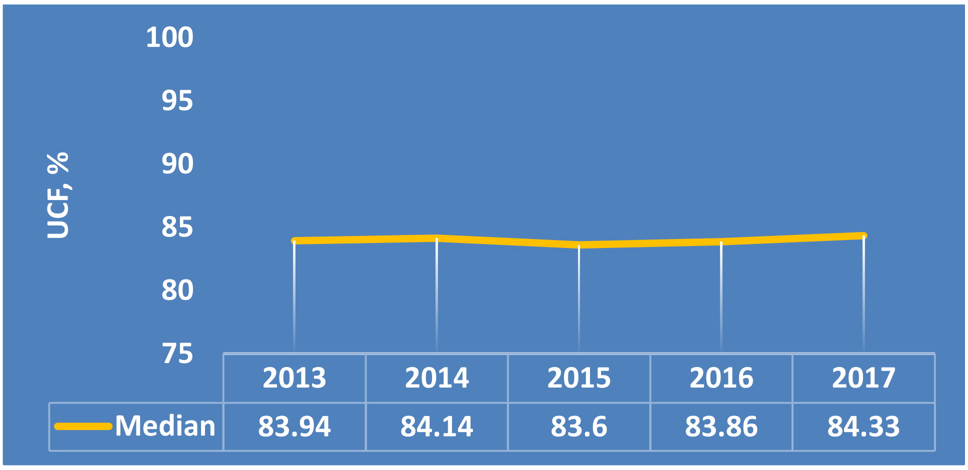
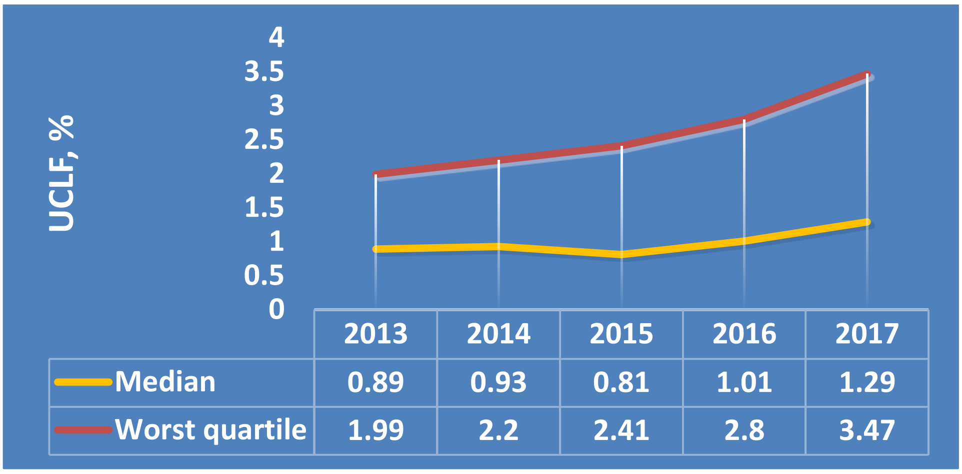


Fig.20 UCF median values history chart of Moscow Centre for 5-year period.

Fig. 20 presents WANO MC median values history of a main indicator, which determines energy generation. This indicator determines a possibility for improvement of energy generation efficiency.

For more detailed analysis of this indicator, please, address section 4.1.

4.4 UCLF – Unit Capability Loss Factor



	2013	2014	2015	2016	2017
Median	0.89	0.93	0.81	1.01	1.29
Worst quartile	1.99	2.2	2.41	2.8	3.47

Fig. 21 WANO MC Median values and lower quartile thresholds history of UCLF throughout 5-year period.

Fig. 21 shows that the threshold values of **UCLF** lower quartile are constantly raising for over 5 years. In 2012 indicator value was about 2% of total power generation, but currently it is about 2,5% and more.

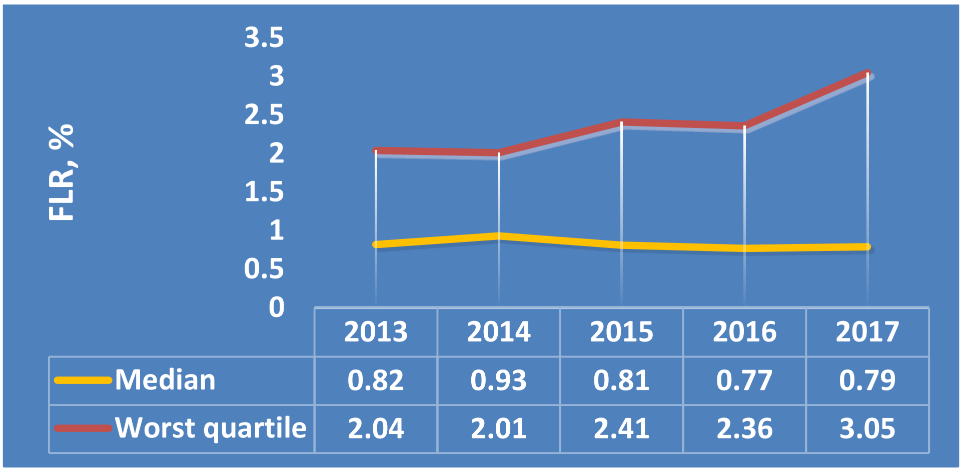
Herewith the median values of energy losses remain constant. This means that good progress of limit values of best quartile also contributes to improvement. This is due to implementation of different approaches to efficient and safe power generation.

Unit capability loss factor also considers downtime due to outage extension. This part of potential (lost) energy generation also changes year to year. Total energy generation loss due to outage downtime in 2017 was approximately 1,605 TW/hour which is approximately 0,4% (in 2016 it was about 2,2%) of the total WANO power generated in 2017.

The following power units require additional attention to their operational modes:

Dukovany 1, 2, 3 – performance indicator value is in worst quartile for more than 2 years: unit 1 – since 15Q4, unit 2 – since 15Q2, unit 3 – since 14Q4.
Novovoronezh 5 – performance indicator values have been in lower quartile throughout more than 5 years, beginning with 12Q1. In 17Q4 the values have slightly improved and currently are lower than median values.
Temelin 1, 2 – performance indicator value of unit 2 is in worst quartile for more than 5 years, starting from 12Q1. PI value of unit No 1 is lower than median, periodically sinking towards worst quartile.
Kursk 2 – a continuous negative trend (from "lower than median" position) towards the lower quartile position since 17Q2.
Kalinin 3, 4 – performance indicator values are in the worst quartile for 5/4 years accordingly: unit No 3 since 12Q1, unit No 4 since 14Q1.
Bushehr 1 – performance indicator value is in the worst quartile since 15Q1.
Kudankulam 1 – performance indicator value is in worst quartile since 15Q1.
South – Ukraine 2 – units are in worst quartile as well since 13Q1 (unit 1 since 15Q2).

4.5 FLR – Forced Loss Rate



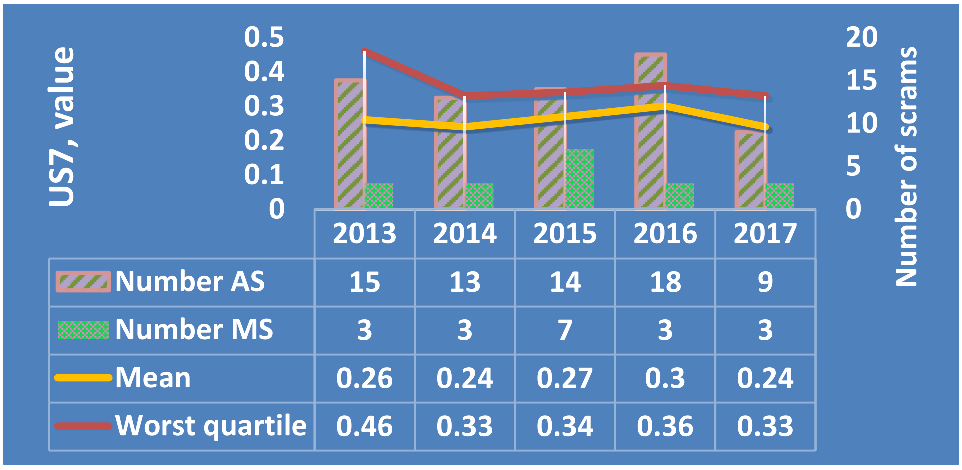
	2013	2014	2015	2016	2017
Median	0.82	0.93	0.81	0.77	0.79
Worst quartile	2.04	2.01	2.41	2.36	3.05

Fig. 22 WANO MC Median values and worst quartile thresholds history of FLR throughout 5-year period

Fig 22 shows that the range between the worst quartile limit and median values of **FLR** throughout the considered 5-year period always tends to slightly expand. At that a relative balance in deviation from the conditional middle value is kept. Positive trend of median values is about 4%, while negative bias of the worst quartile threshold values is around 50%. Total forced energy generation loss occurred due to equipment failures at NPPs of Moscow Centre in 2017 was around 13,274 TW/h.

For more detailed analysis of this indicator, please, see section 4.1.

4.6 UA7 and US7 – Unplanned Automatic Scrams per 7000 Hours Critical and Unplanned Reactor Scrams per 7000 Critical (Automatic + Manual)



	2013	2014	2015	2016	2017
Number AS	15	13	14	18	9
Number MS	3	3	7	3	3
Mean	0.26	0.24	0.27	0.3	0.24
Worst quartile	0.46	0.33	0.34	0.36	0.33

Fig. 23 Data on scrams actuation at power units over five-year period.

Fig. 23 shows changes of US7 average value over five-year period and presents lower quartile threshold values. Besides the scram actuation rate at WANO MC power units is presented at the chart. More derailed data on scrams actuation at NPPs of Moscow Centre are given in the **table 13**.

Table 13

Item No	NPP	Unit	Date	Scram type/rate (DES database)	
				Automatic	manual
			17Q1		
1	Rovno	3	2017	1	
			17Q2		
2	Leningrad	4	2017	1	
			17Q3		
3	Kola	4	2017		1
4	Rovno	4	2017	1	
5	Leningrad	3	2017	1	
6	Kudankulam	2	2017		1
7	Loviisa	2	2017		1
8	Vaigach (Atomflot)	-	2017	1	
			17Q4		
9	Vaigach (Atomflot)	-	2017	1	
10	Tianwan	1	19.10.2017	1	
11	Kudankulam	1	10.12.2017	1	
12	Khmelnitski	2	2017	1	
Total	11 NPPs			9	3
				12	

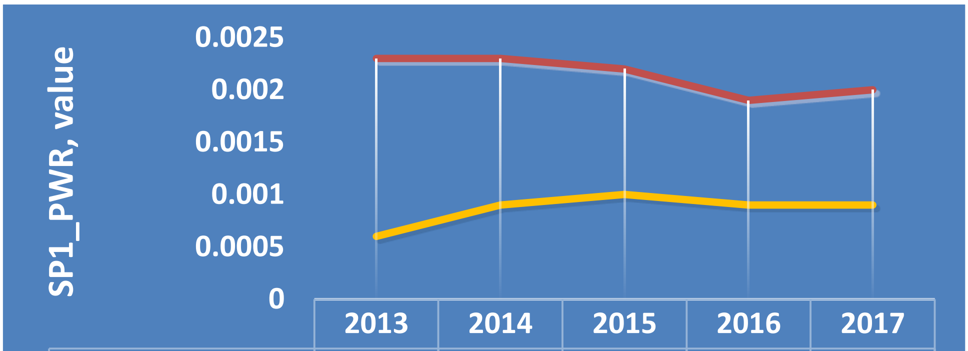
As we can see, the latest trend of scrams number tends to sink, which is positive dynamic. This is what attention must be given to.

In comparison with the total world number of scrams initiation WANO Moscow Centre takes a satisfactory position. Average indicator value of the regional centre is twice lower than total value. And Moscow Centre's percent of individual and industrial-level target achievement is the highest across WANO - 97,1% and 82,9% accordingly.

4.7 GRLF – Grid Related Loss Factor

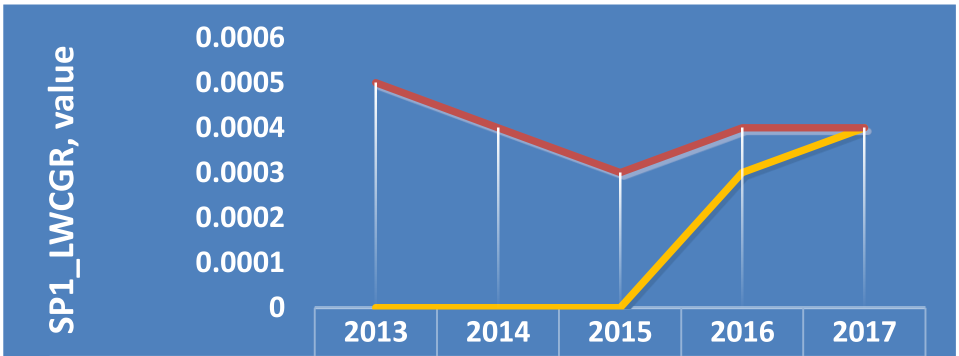
Usually the median value of this indicator is zero both for WANO MC and for the whole world. Herewith approximately 18-19 power units have quarterly power loss due to grid instability of **2,8%**/quarter. In 2017 total power generation losses due to grid instability made **0,6%** (**0,026 TW/h**) of total electricity generation across MC.

4.8 Safety Systems Performance: HPSI (SP1), Auxiliary Feedwater System (SP2), Emergency AC Power System (SP5)



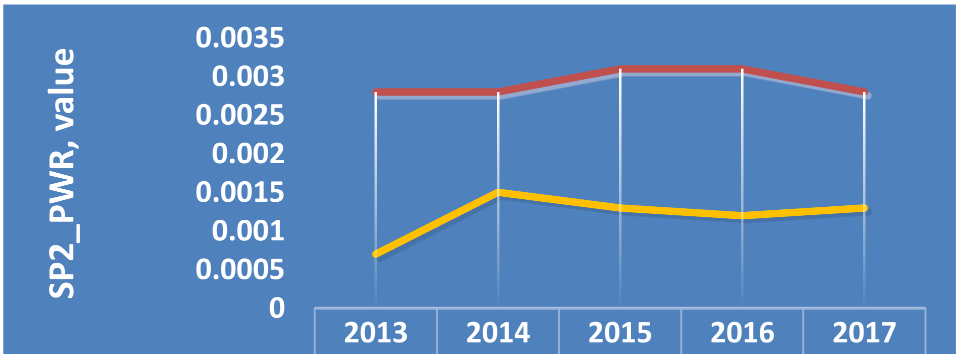
	2013	2014	2015	2016	2017
Median	0.0006	0.0009	0.001	0.0009	0.0009
Worst quartile	0.0023	0.0023	0.0022	0.0019	0.002

Fig. 24 Median values history and worst quartile threshold values history of SP1 PWRs across WANO MC over five-year period.



	2013	2014	2015	2016	2017
Median	0	0	0	0.0003	0.0004
Worst quartile	0.0005	0.0004	0.0003	0.0004	0.0004

Fig. 25 Median values history and worst quartile threshold values history of SP1 LWCGR group over five-year period



	2013	2014	2015	2016	2017
Median	0.0007	0.0015	0.0013	0.0012	0.0013
Worst quartile	0.0028	0.0028	0.0031	0.0031	0.0028

Fig. 26 Median values history and worst quartile threshold values history of SP2 PWRs over five-year period

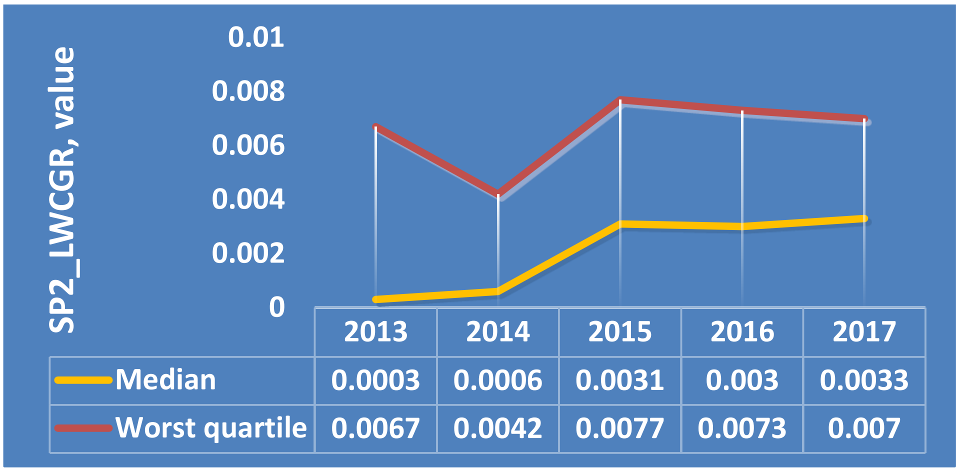


Fig. 27 Median values history and worst quartile threshold values history chart of SP2 WANO MC LWCGR group over five-year period.

Fig. 28 Median values history and worst quartile threshold values history chart of WANO MC SP5 over five-year period.

A number of safety systems availability indicators was developed to perform safety functions availability analysis. **Fig. 24 – 28** show median values and worst quartile history charts for a number of these indicators. These indicators describe availability of the following safety systems:

SP1 – high-pressure safety injection system (HPSI);

SP2 – emergency and auxiliary feedwater systems;

SP5 – emergency AC power system – emergency diesel-generators.

A comprehensive counting mechanism is applied to calculate these indicators, which includes parts describing equipment reliability. The following types of equipment unavailability are considered:

- planned unavailability (planned maintenance of safety systems equipment);
- unplanned unavailability (time of unavailability of the equipment to perform its prescribed function due to failures);
- fault exposure unavailability (part of equipment reliability theory also describing the safety systems equipment failures).

Data on safety systems availability for WANO MC over 2017 are expressed in figures and provided in **table 14**.

Table 14. Total unavailable hours of safety systems equipment over 2017.

SP1 – high-pressure safety injection system HPIS	
Planned unavailability, h	5114.03
Unplanned unavailability, h	740.5
Fault exposure unavailable hours	1060
SP2 – emergency and auxiliary feedwater systems	
Planned unavailability, h	2318.08
Unplanned unavailability, h	380.77
Fault exposure unavailable hours	467.5
SP5 – emergency AC power system – emergency diesel-generators	
Planned unavailability, h	11447.1
Unplanned unavailability, h	2168.2
Fault exposure unavailable hours	701.3

WANO Performance Indicators approach is not intended to testify for failure of SS equipment to perform safety functions over a power unit or a whole station. But it allows to assess time (hours) of SS equipment unavailability to perform its prescribed function, and also allows to identify improvement of operational and maintenance practices.

4.9 CRE – Collective Radiation Exposure

This monitoring area is related to radiological safety at NPPs, to be more precise, to the potentially hazardous impact of ionizing radiation on station personnel. This area is included in scope of WANO – CRE, an indicator of collective radiation exposure of personnel. **Fig. 29** and **30** provide data on median value and worst quartile values history for PWR and LWCGR over 5-year period.

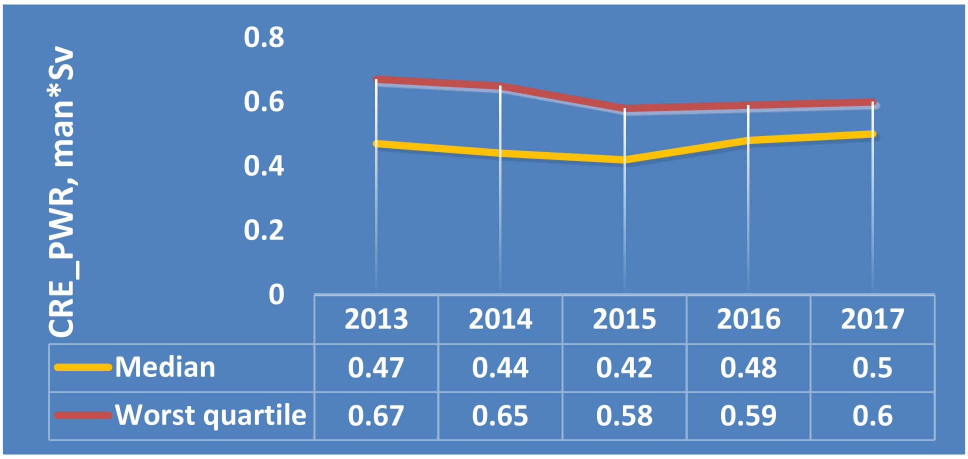


Fig. 29 Median values history and worst quartile threshold values history chart of WANO MC CRE for PWRs over 5 – year period.

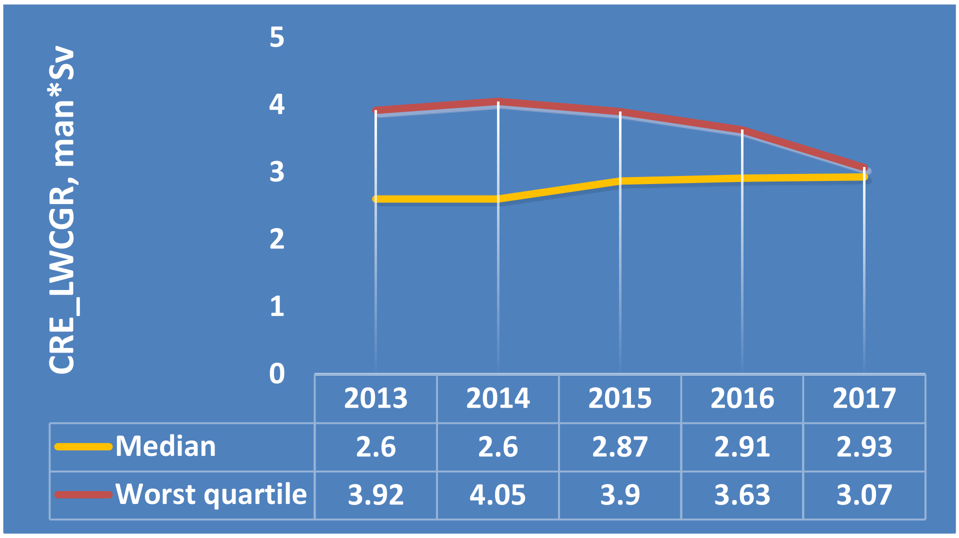


Fig. 30 Median values history and worst quartile threshold values history chart of WANO MC CRE for RBMKs over 5 – year period.

Works on life extension, modifications, and fuel defects, loss of integrity of equipment with radioactive media bias value of this indicator. This data is clearly visible in median values increase, especially over the last few years.

To express it in figures, WANO MC personnel external exposure over 2017 was **60,13 man/Sv**, and personnel internal exposure was **0,11 man/Sv**. Overall collective radiation exposure over a regional centre was about **60,24 man/Sv**.

Power units with PWRs in lower quartile for a longer period are as follows: **Novovoronezh (units 4,5), South-Ukraine (units 1,2,3), Armenian (unit 2)**. High values are typical for **Kola NPP**: **unit 1** has been in worst quartile for 5 years, and the rest of the **units 2, 3, 4** periodically change their position in between of the worst quartile and worse than median. There is a worsening at **Kalinin NPP unit 1.** For it has been in the worst quartile since 16Q2 with negative trend. Among power units with LGCWRs **Kursk NPP** has to be noted as one with the highest values in LWCGR group.

4.10 FRI – Fuel Reliability

As of the end of 2017 averages of nuclear fuel reliability tend to a slight positive dinamic. **Fig. 31** and **32** represent history of median values and worst quartile threshold values of fuel reliability indicator – **FRI**.

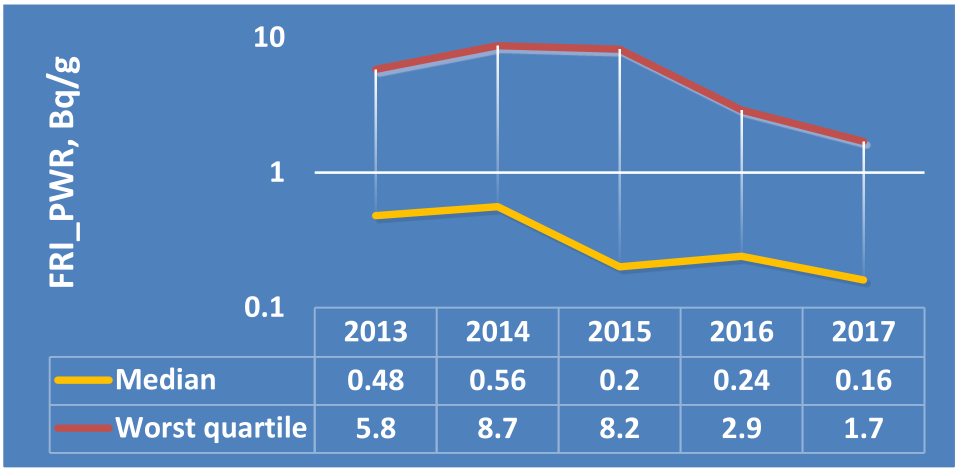


Fig. 31 History of median values and worst quartile threshold values of FRI for WANO MC PWRs over 5-year period.

The data relates to PWR and LWCGR reactor facilities. The considered values (median and quartile threshold value) are acceptable – lower than fuel defects threshold (19 Bq/g for PWR) with a slight positive trend.

Unit 1 of **Kalinin NPP** had the highest FRI value in 4th quarter of 2017. This value exceeded fuel defect threshold by more than 25 times. **Kola 1,2** (since 12Q1) and **Temelin 1,2** (since13Q4) were also among the stations showed high indicator values.

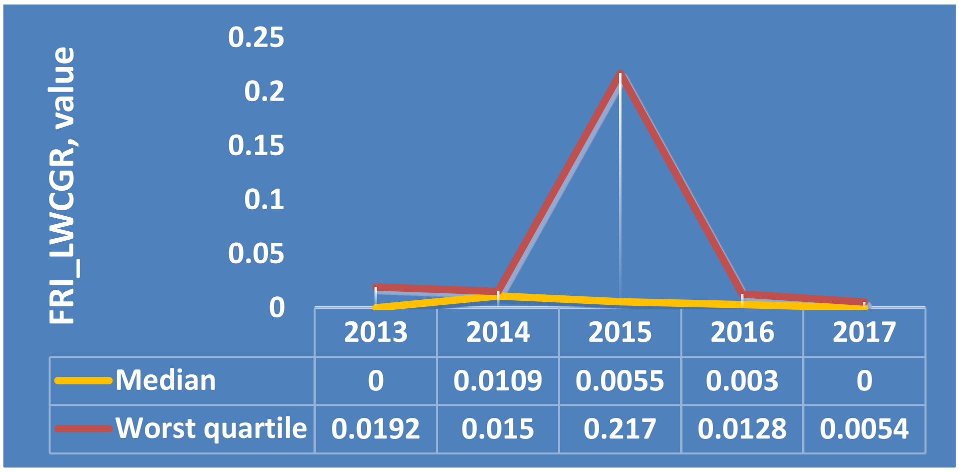


Fig. 32 History of median value and worst quartile thresholds of FRI for WANO MC LWCGR group over 5-year period.

4.11 CPI – Chemical Performance Indicator

Current chemical indicator values of WANO MC are at an acceptable level. Efforts on indicator modification continue. Their completion is planned for 2018. Details on CPI values distribution are provided in Appendix 1.

4.12 Total Industrial Safety Accident Rate (TISA2), for Personnel Assigned to Work at Station (ISA2) for Contractor Personnel (CISA2)

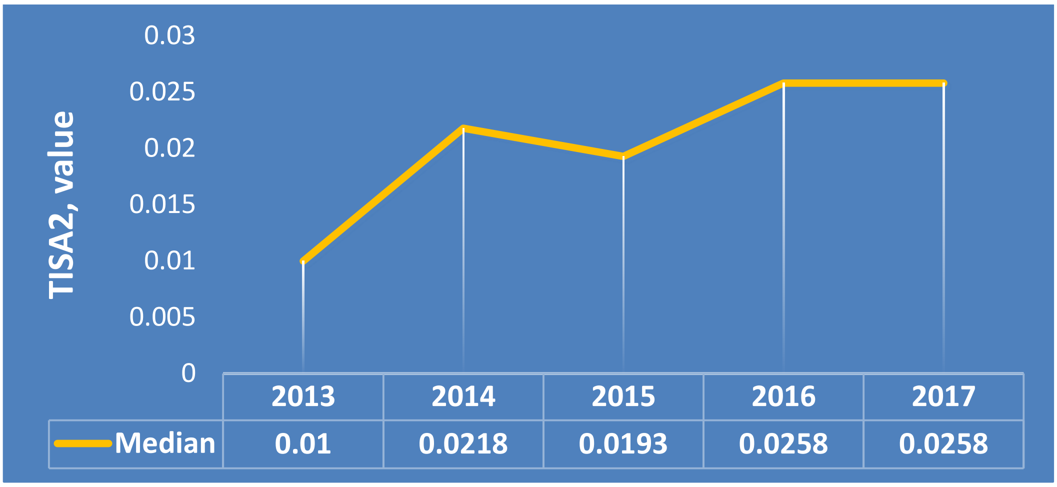


Fig. 33 WANO MC median values history for TISA over 5-year period.

Generalized indicator (**TISA2**) was implemented in WANO PI system since 2016. It monitors time lost by all personnel (station personnel + contractors personnel), involved in performance at station, due to safety accidents. **Fig. 33** shows chart of median value history of this indicator over the 5-year period.

The highest values on lost-time accident indicators belong to the stations of European part of Moscow Centre: **Loviisa, Paks, Dukovany, Temelin, Mochovce, Bohunice and Bushehr NPPs**, which are in worst quartile for a longer period (more than 3 years).

Unfortunately, the existing methodology of indicators calculation, which indirectly describes station industrial safety and accidents status, doesn't allow for a high-quality analysis of particular cases of accidents. For example, despite their worst indicator values, these stations didn't face fatalities, which took place at stations of WANO MC.

One fatality occurred in 2017 to contractor's personnel (Leningrad NPP: 1 OA in 1st quarter).

Occupational accidents, occurred in 2017 were divided in groups as follows:

- number of lost-time accidents involving days away from work for utility personnel assigned to the station/contractors personnel – 3/3;

- number of restricted-time accidents involving days of restricted work for utility personnel assigned to the station/contractors personnel – 18/23;

- number of work-related fatalities for utility personnel assigned to the station/contractors personnel – 0/1.

Mean indicators value is almost 3 times below the world average.

5. WANO PI Programme Implementation at WANO MC in 2017

5.1 WANO PI Programme Objective

As a part of WANO Long-Term Plan, “Performance Indicators” Programme pertains to direction one, which is to provide support and set high performance standards for the existing world nuclear fleet.

Following-up this direction the WANO PI Programme addresses the main task on indicators data collection and dissemination to allow stations to set reasonable goals, control and measure performance indicators and benchmark to the best performance examples of the industry.

Implementation criteria is the improvement of data collection due to reporting improvement and further development of indicators definition to ensure that 95% power units provide qualified data on all the performance indicators.

As of the end of 2017 it can be concluded, that 100% power units provide qualified data on all performance indicators.

5.2 Internal Programme Indicators (Metrics)

Fig. 34 provides data on internal indicators (metrics) of PI Programme for 2017. Internal indicators analysis reveals one AFI related to timely data communication from NPP to DES database. Failure to timely report (within 45 days) took place at a number of nuclear power plants:

3rd quarter – Kozloduy NPP (unit No 5, 6); Beloyarsk NPP (unit No 3); Kalinin NPP (power units 2,3,4), Kola NPP (power units 1,2,3,4).

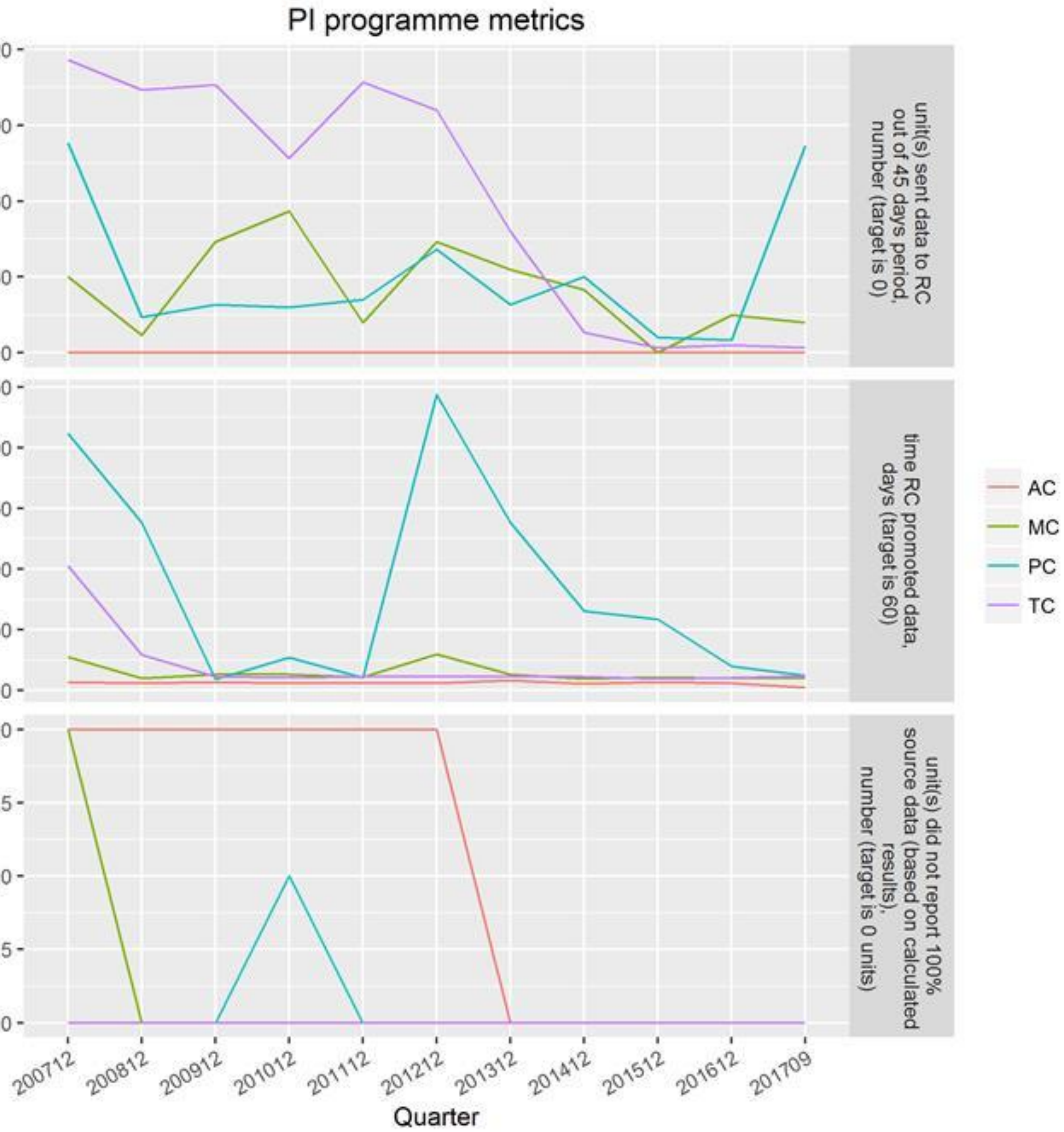


Fig.34 PI Programme internal metrics

5.3 Implementation Status of the Activities Planned for 2017

Table 15 describes implementation status of the planned PI Programme activities as for the end of 2017.

Table 15

Item No	Activity	Dates	Comment
1.3.6.1	Indicators data collection and analysis, 4 times a year	2017	Done quarterly
1.3.6.2	Data approval and correction in DES system, 4 times a year	2017	Done quarterly

Item No	Activity	Dates	Comment
1.3.6.3	Preparation of materials on performance indicators prior to the next Peer Review, total number of activities planned – 7.		
1.3.6.3.1	Preparation of materials on performance indicators prior to Kola NPP Peer Review	February 2017	Done
1.3.6.3.2	Preparation of materials on performance indicators prior to Dukovany NPP Peer Review	March 2017	Done
1.3.6.3.3	Preparation of materials on performance indicators prior to Armenian NPP Peer Review	August 2017	Done
1.3.6.3.4	Preparation of materials on performance indicators prior to Bohunice NPP Peer Review	September 2017	Done
1.3.6.3.5	Preparation of materials on performance indicators prior to Smolensk NPP Peer Review	October 2017	Done
1.3.6.3.6	Preparation of materials on performance indicators prior to Kursk NPP Peer Review	November 2017	Done
1.3.6.3.7	Preparation of materials on performance indicators prior to Kozloduy NPP Peer Review	November 2017	Done
1.3.6.4	Rapid assessment of NPPs for the purpose of T&D Programme to conduct SMs, at least 3 times a year	2017	Done quarterly on a regular basis
1.3.6.5	Indicators comparative analysis to perform convergence check, jointly with OE group, at least 2 times a year.	2017	Done on a regular basis
1.3.6.6	Analysis of Moscow Centre NPPs performance indicators, 4 times a year	2017	Done quarterly on a regular basis
1.3.6.7	Preparation of annual PI report	March 2018	Done
1.3.6.8	Identification of NPPs in need for support, 4 times a year	2017	Done quarterly on a regular basis

Item No	Activity	Dates	Comment
1.3.6.9	Conduct workshops at NPP in need of support through T&D Programme, 2 times a year	2017	Done. WS at Kursk NPP – April, WS at Kalinin NPP - December
1.3.6.10	Preparation of indicators comparative analysis upon request from stations and companies, 4 times a year	2017	Done on a regular basis
1.3.6.11	Hosting a WANO PI workshop involving responsibles from NPPs	June 2017	Done
1.3.6.12	Participation in workshop for the purpose of WANO and IAEA cooperation	2017	Done
1.3.6.13	Interaction with other RCs and London Office on the matters of performance indicators	2017	Done on a regular basis
1.3.6.14	Benchmarking with other RCs for the purpose of exchange of experience in PI Programme. Participation in workshops or meetings on PI held in other RCs and London Office.	2017	No activities conducted
1.3.6.14.1	Meeting on performance indicators	February 2017	Done
1.3.6.14.2	Participation in PI workshop	2017	Done
1.3.6.14	Taking part in the process of identification of interaction and support level of WANO Moscow Centre	2016	Done on regular basis
1.3.6.15	Participation in a WANO MC process for identification of levels of interaction and support to NPPs.	2017	Done
1.3.6.16	Efforts taken to optimize CRE target value for LWCGR group	2017	Partially done. Work completion planned for 2018

It is worthy of note that positive trends in PI Programme deployment and usage of its results over 2017 were identified. The results of PI reports were more actively used during work of both WANO MC secretariat and WANO activities. This contributed to additional attention and respect paid by NPPs managers to plant performance indicators.

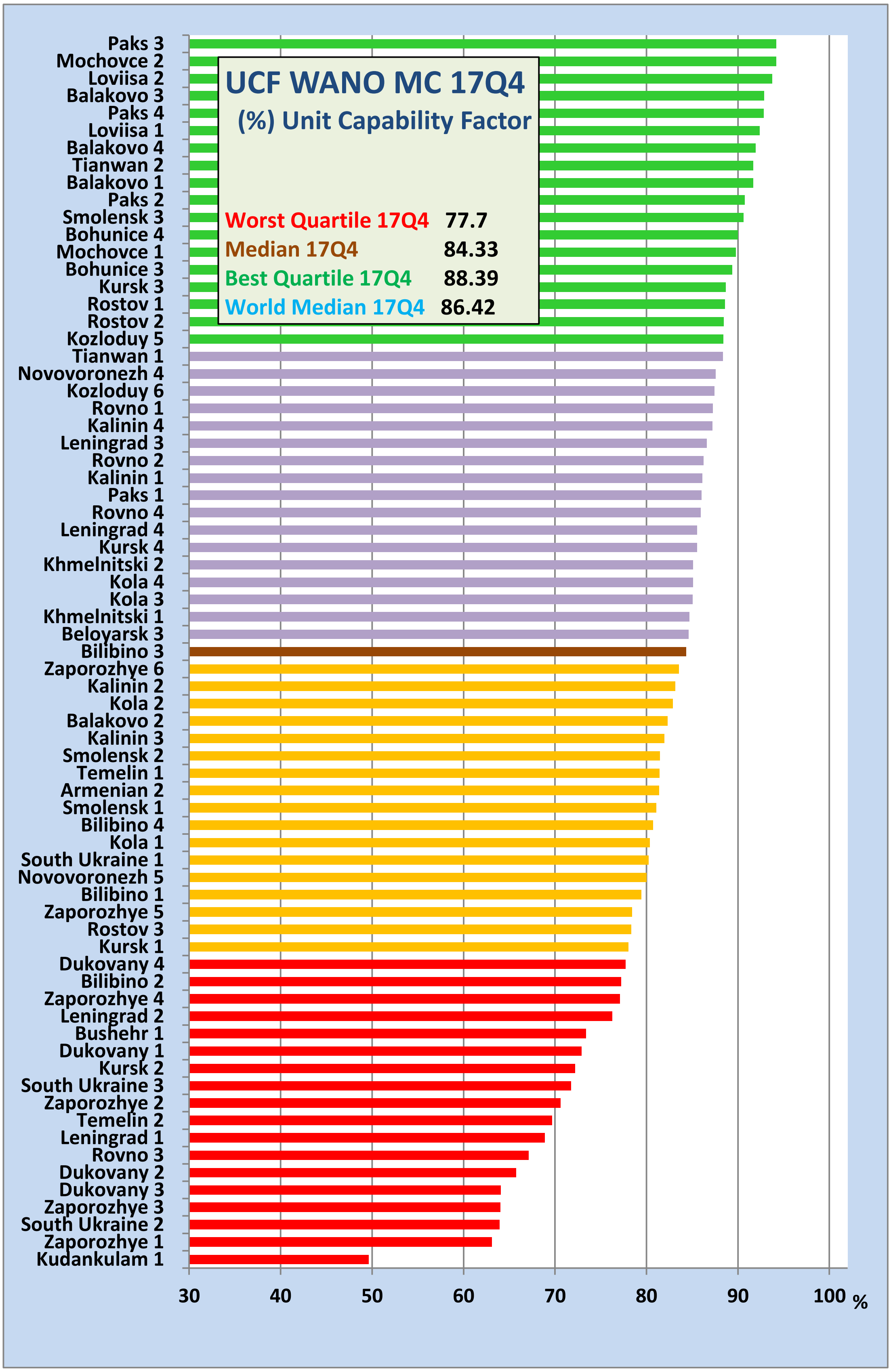
Additionally, implemented:

- A number of retreats: 1 PI TSM (Kursk NPP, April 2017) and 1 workshop at Kalinin NPP;
- PI reports results were actively used during PR and DIR.

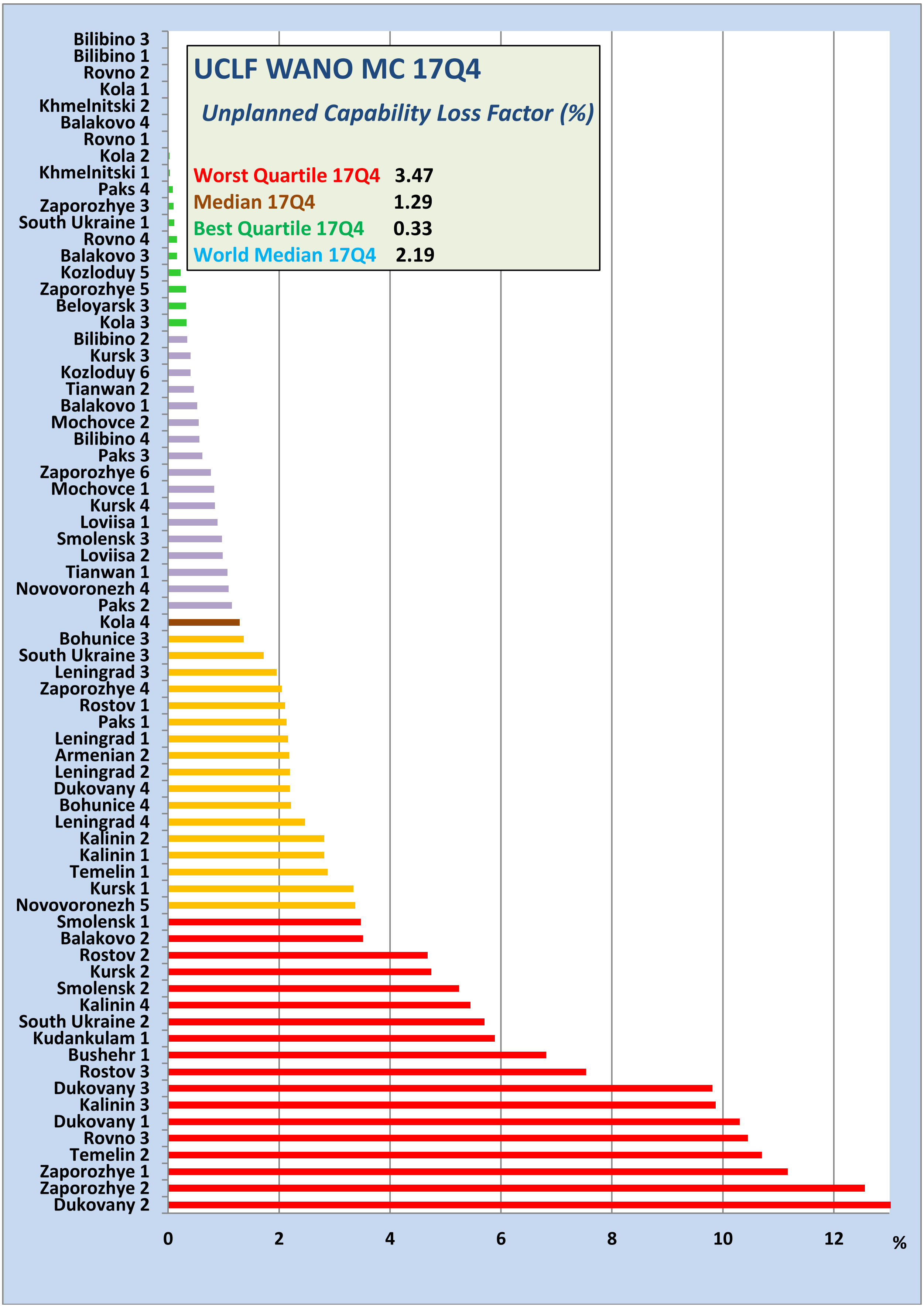
Appendix 1: WANO PI Chart for the 4th Quarter 2017

Power Generation Indicators

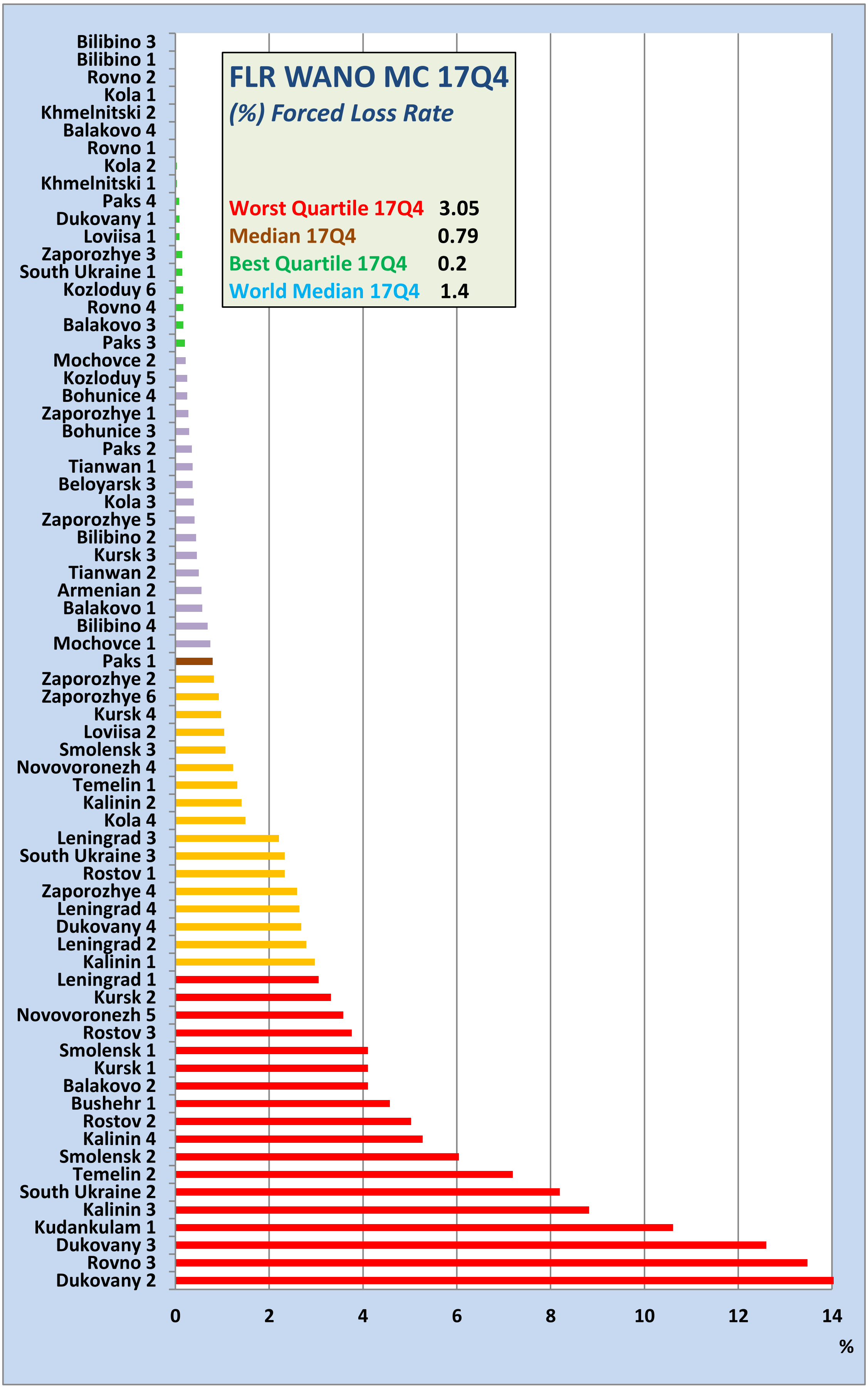
UCF – Unit Capability Factor



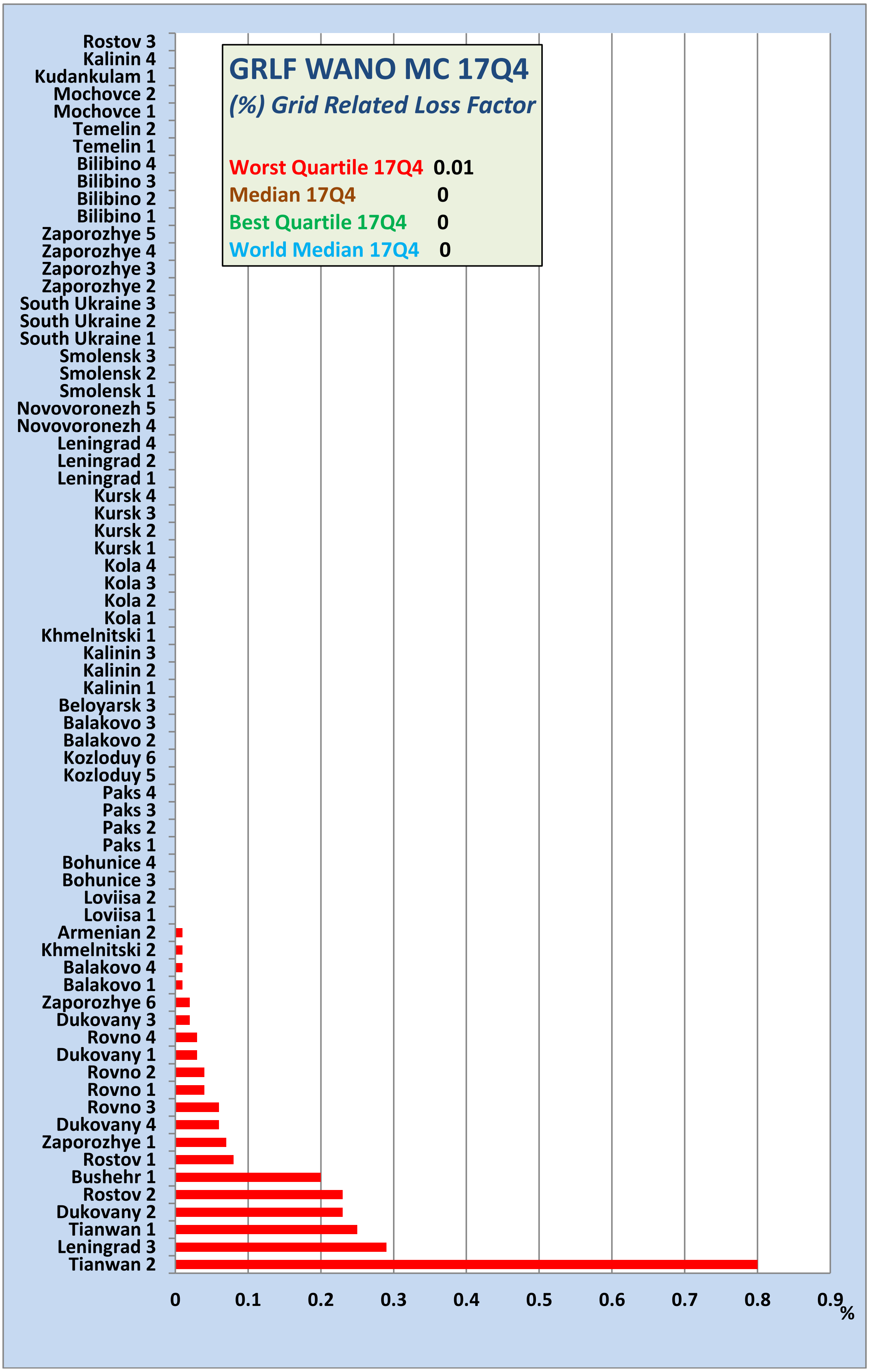
UCLF - Unit Capability Loss Factor



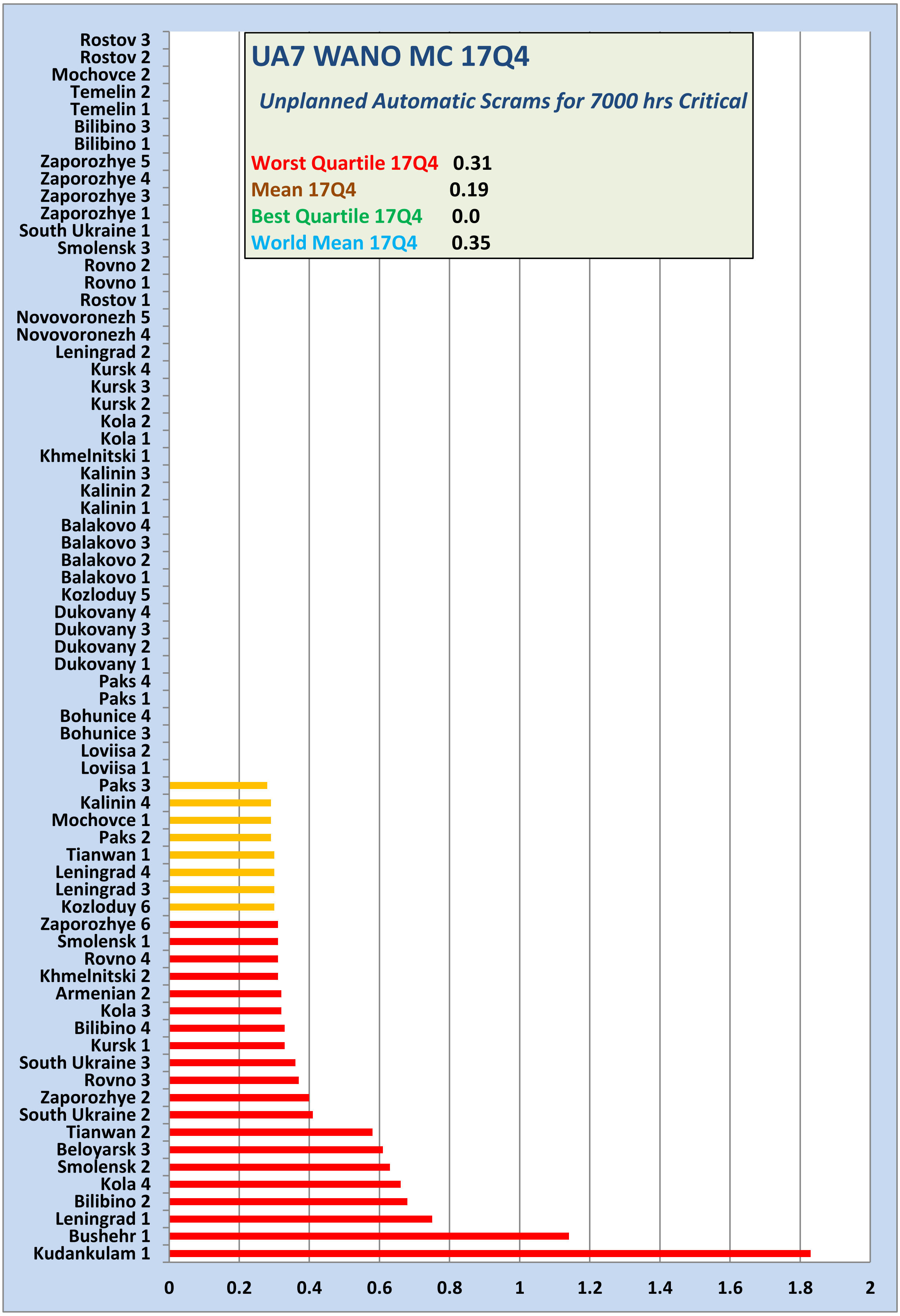
FLR – Forced Loss Rate



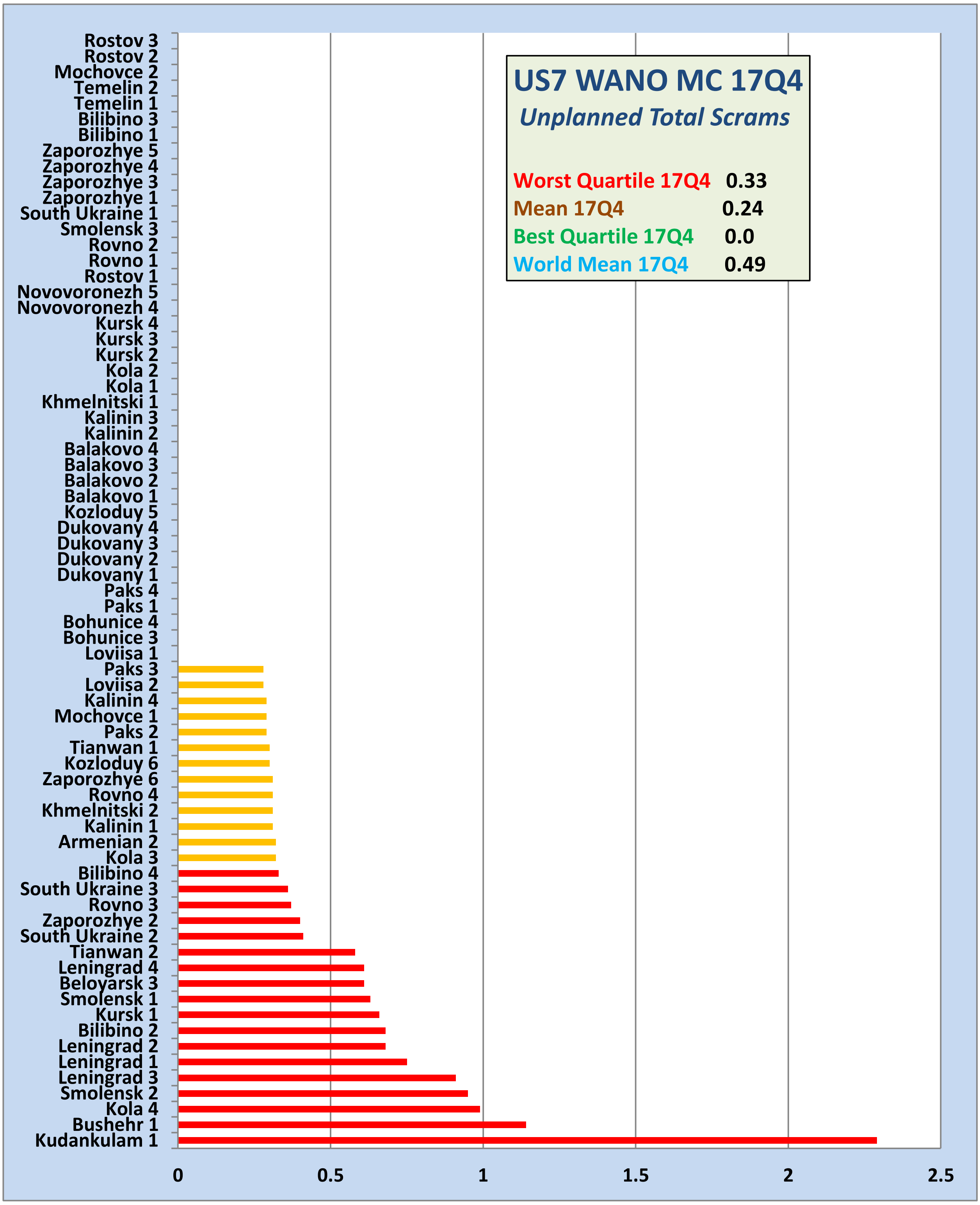
GRLF – Grid Related Loss Factor



UA7 - Unplanned Automatic reactor scrams per 7000 hours critical

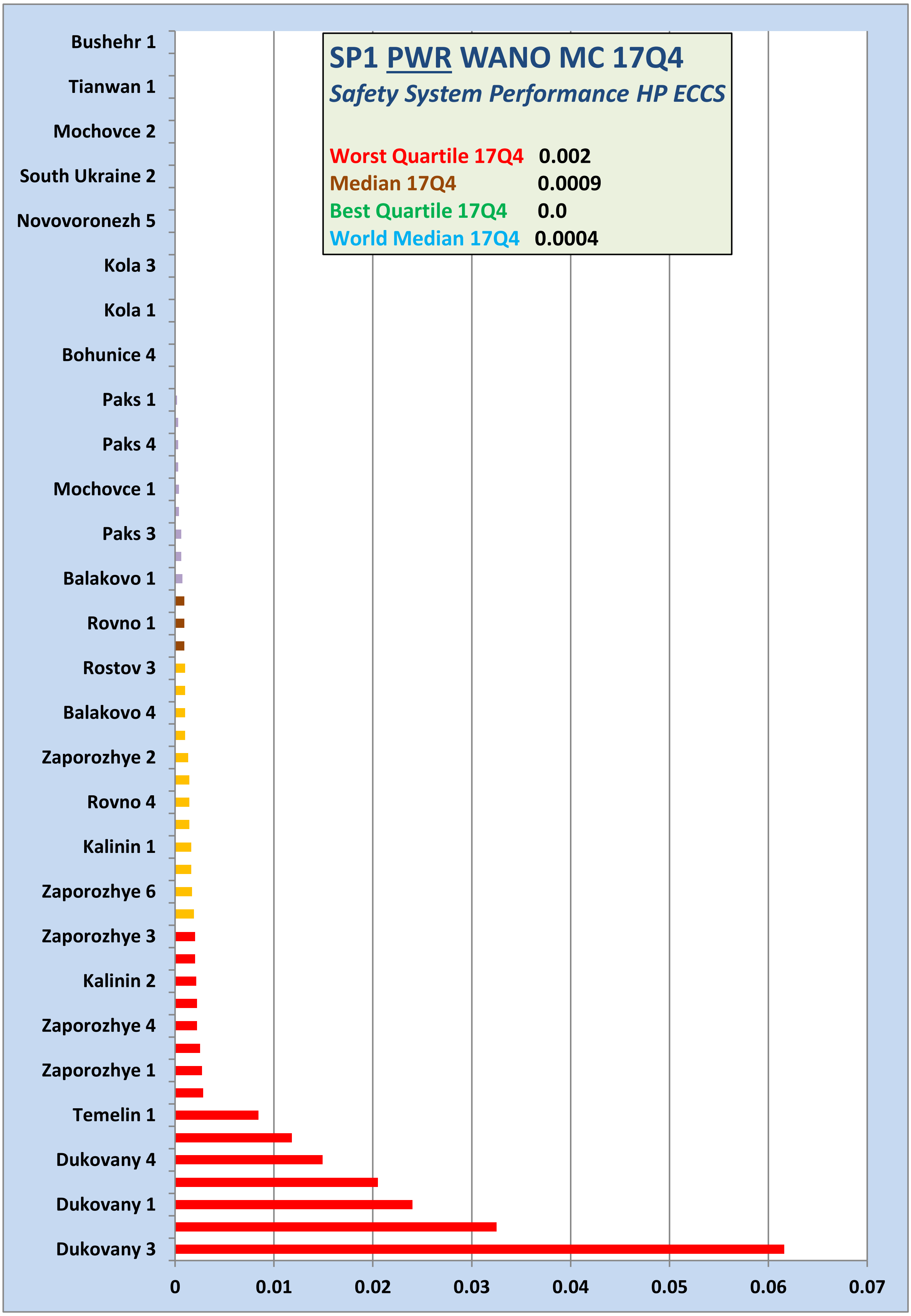


US7 –Unplanned Total scrams per 7000 hours critical (automatic + manual)

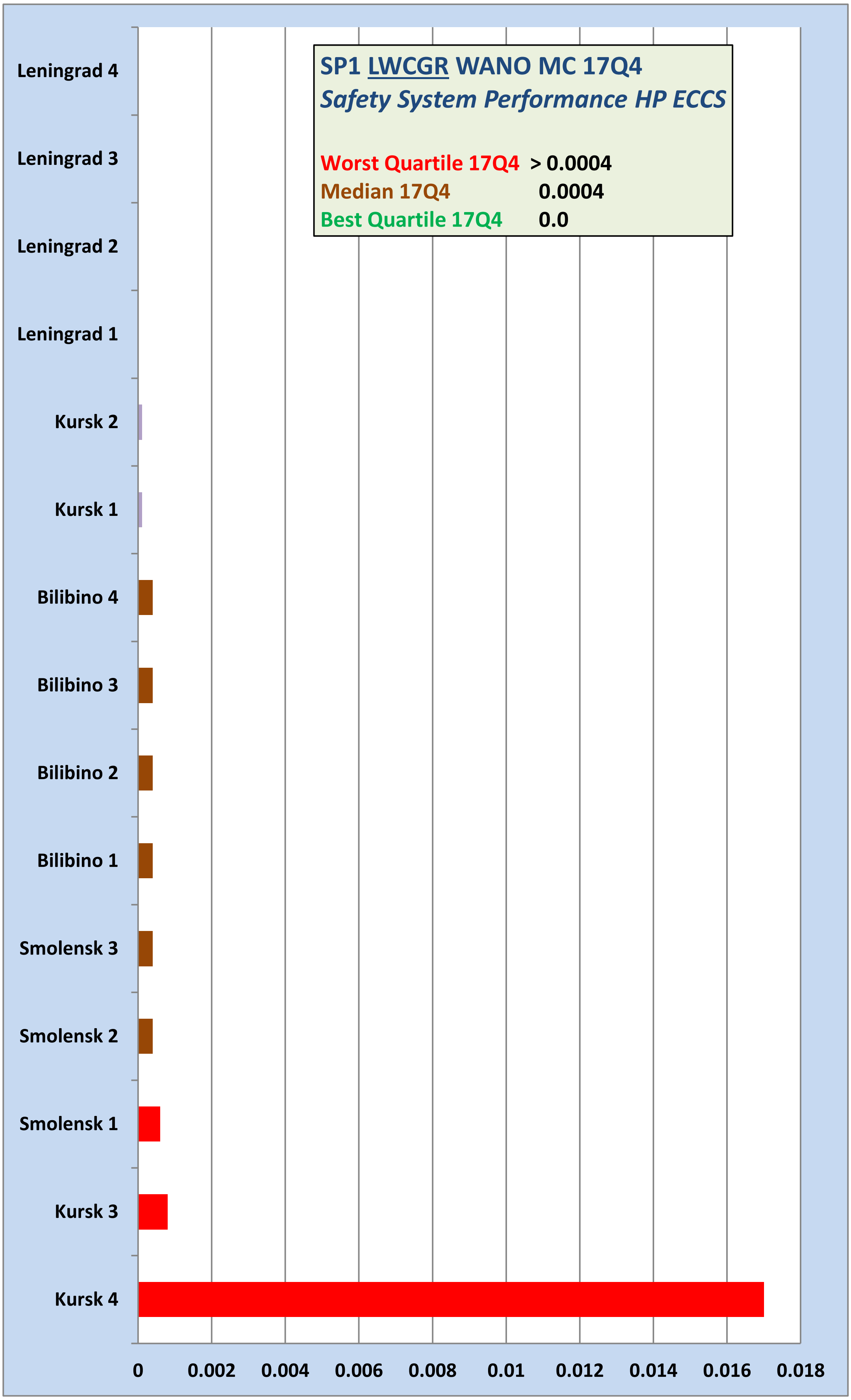


Safety Systems Performance Indicators

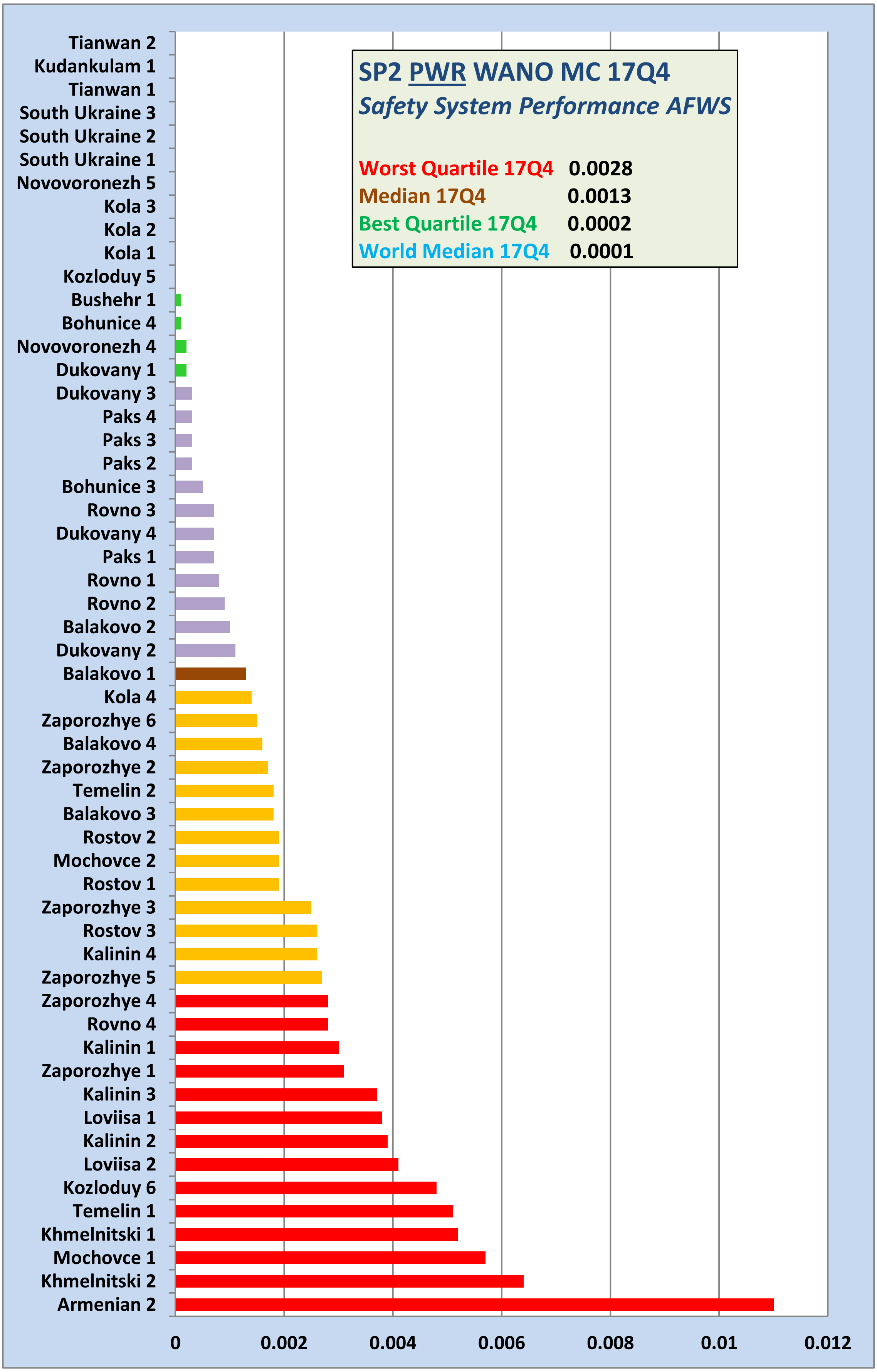
SP1 – High Pressure Heat Removal System Performance (PWR)



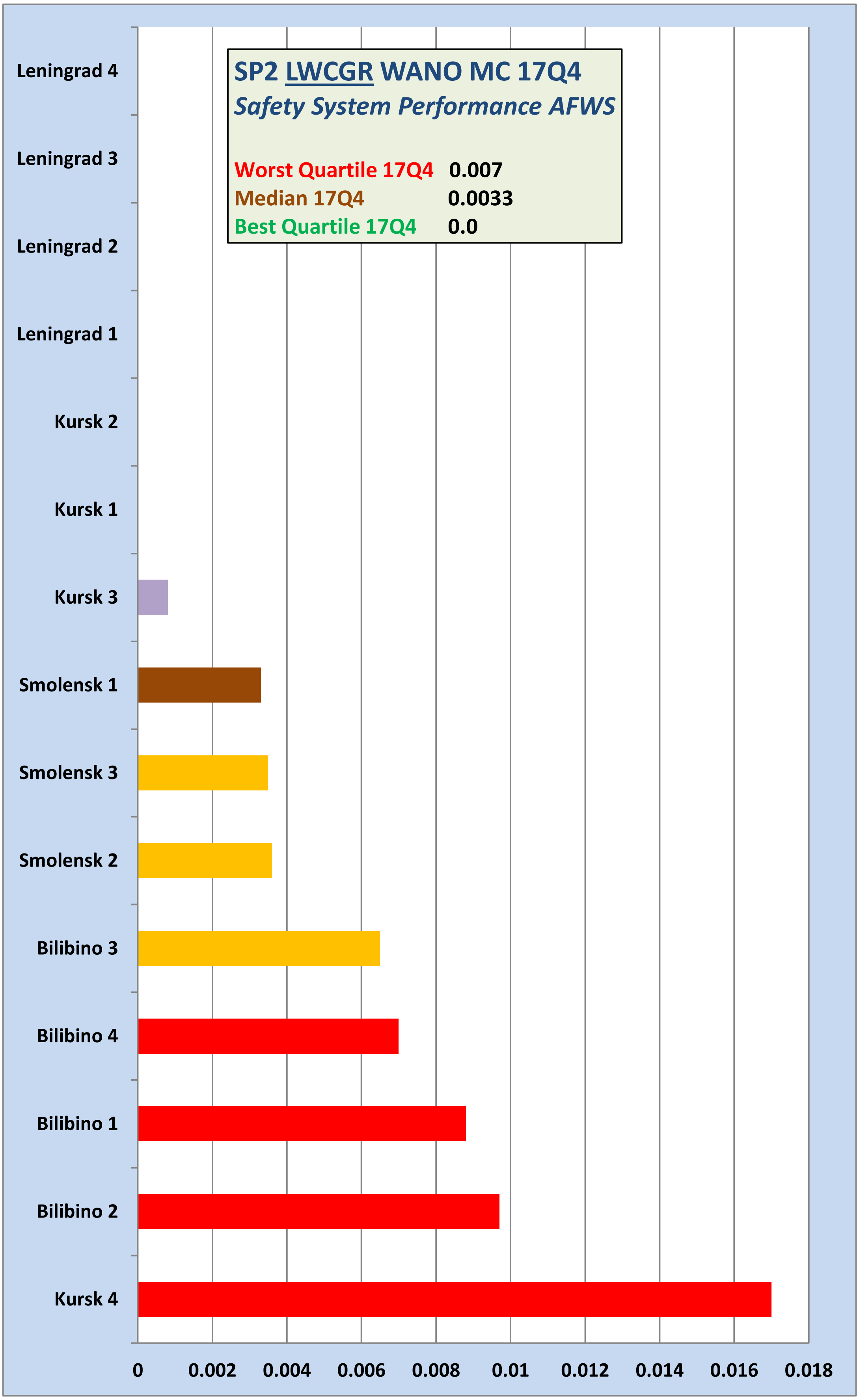
SP1 – SSPI High pressure emergency core cooling systems performance (LWCGR)



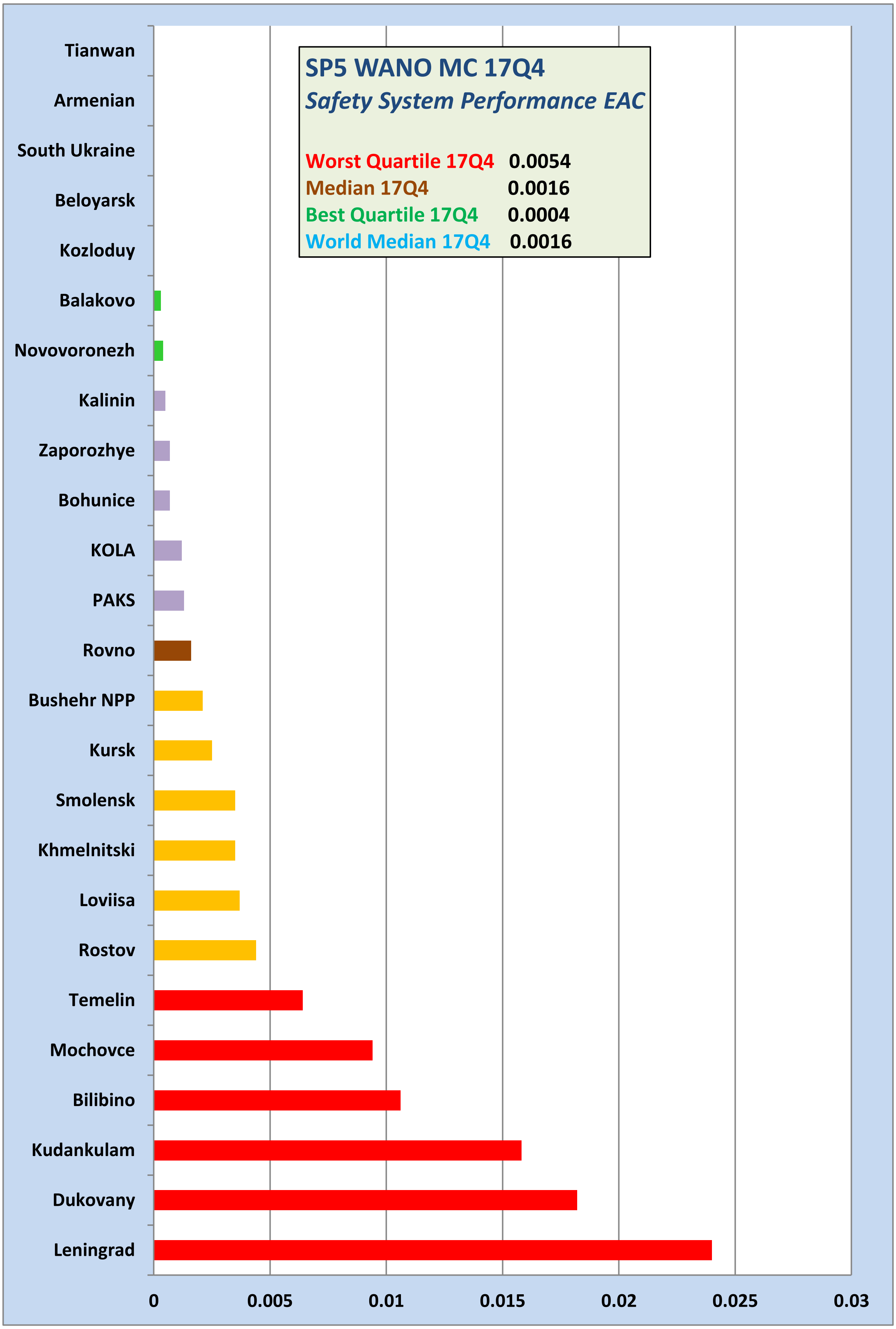
SP2 – Auxiliary feedwater systems performance (PWR)



SP2 – Auxiliary feedwater systems performance (LWCGR)

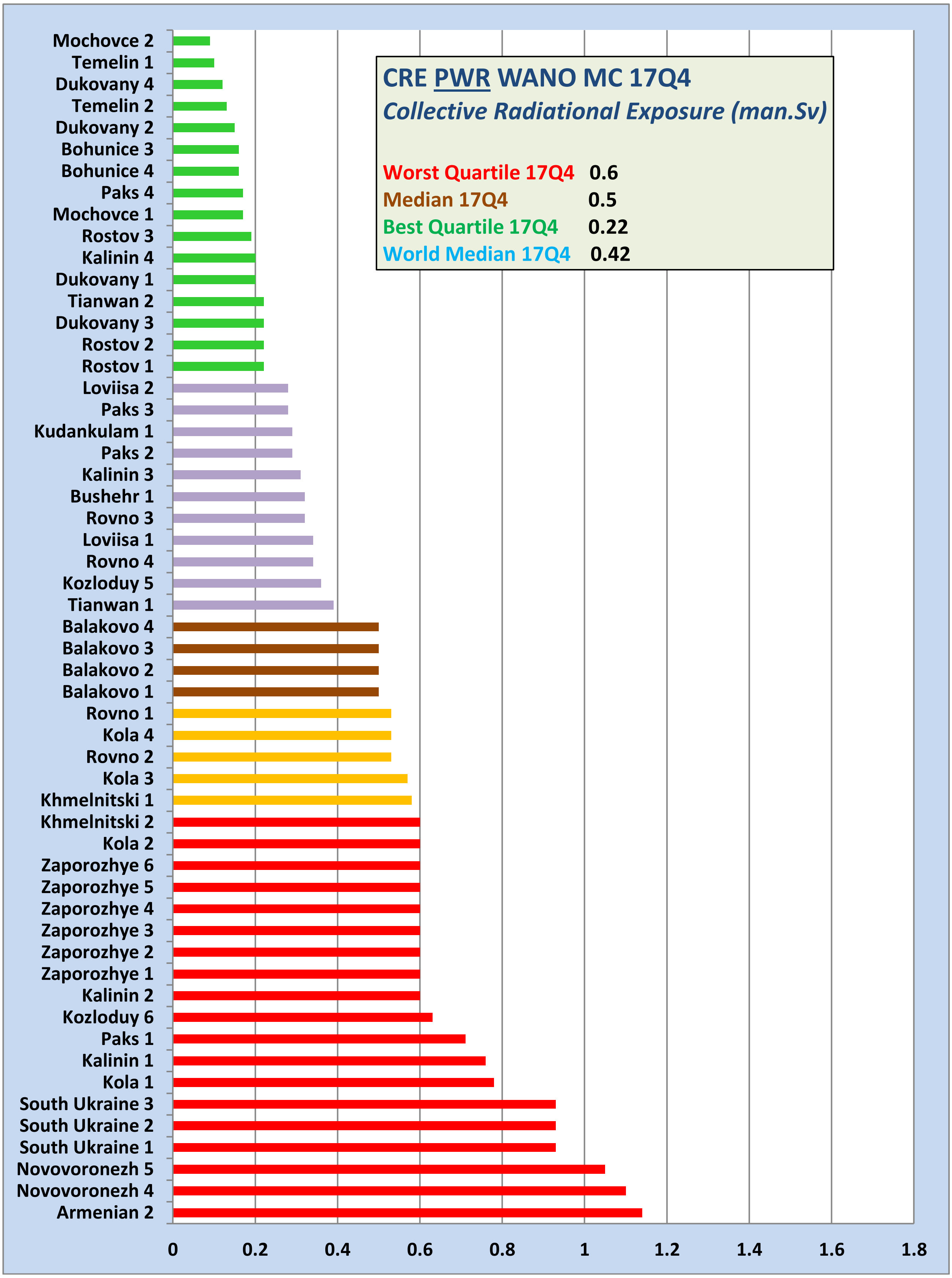


SP5 (EAC) – Emergency AC power systems performance (DG)

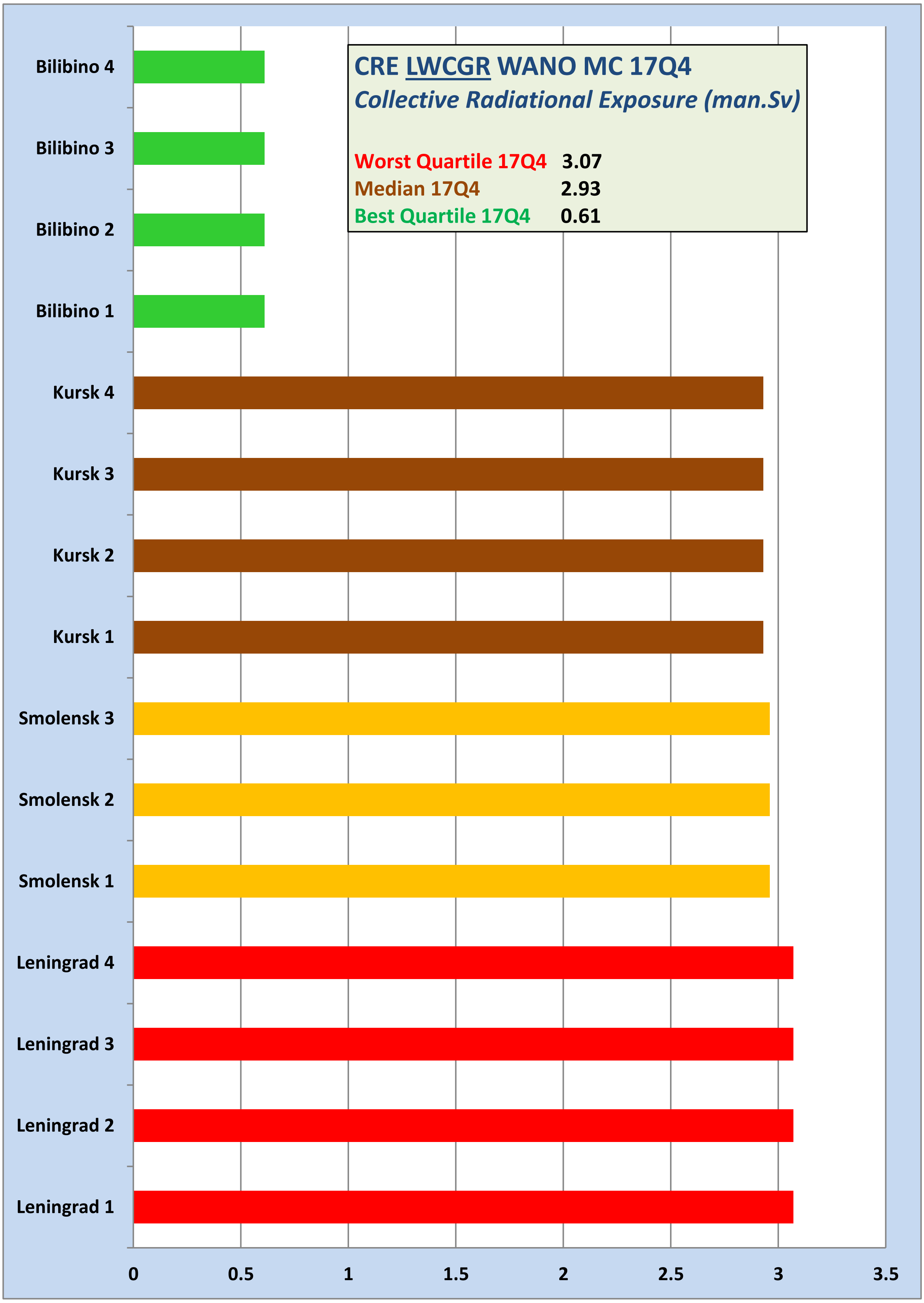


Radiation Protection, Fuel Reliability, Chemistry Performance Indicators

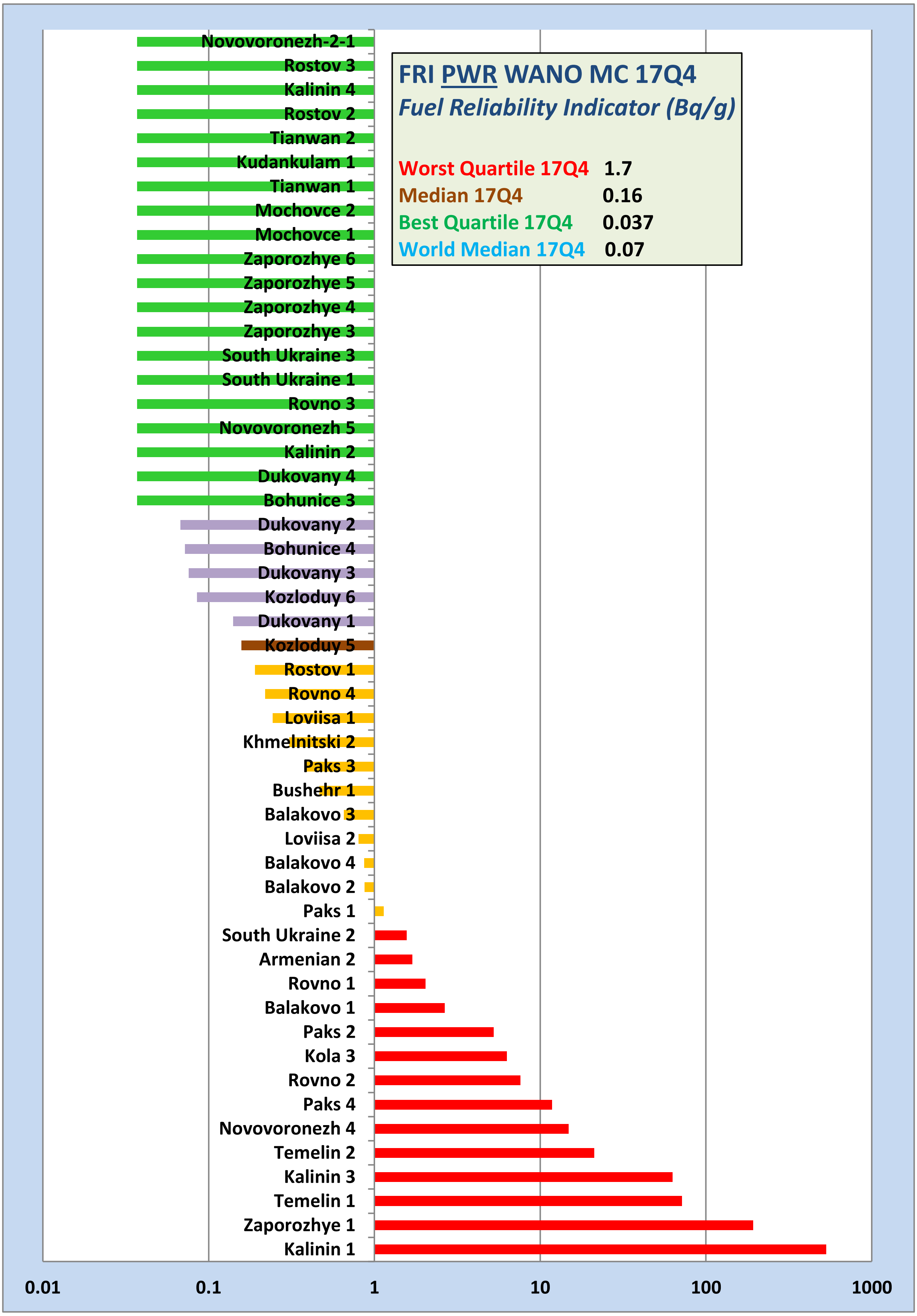
CRE – Collective Radiation Exposure (PWR)



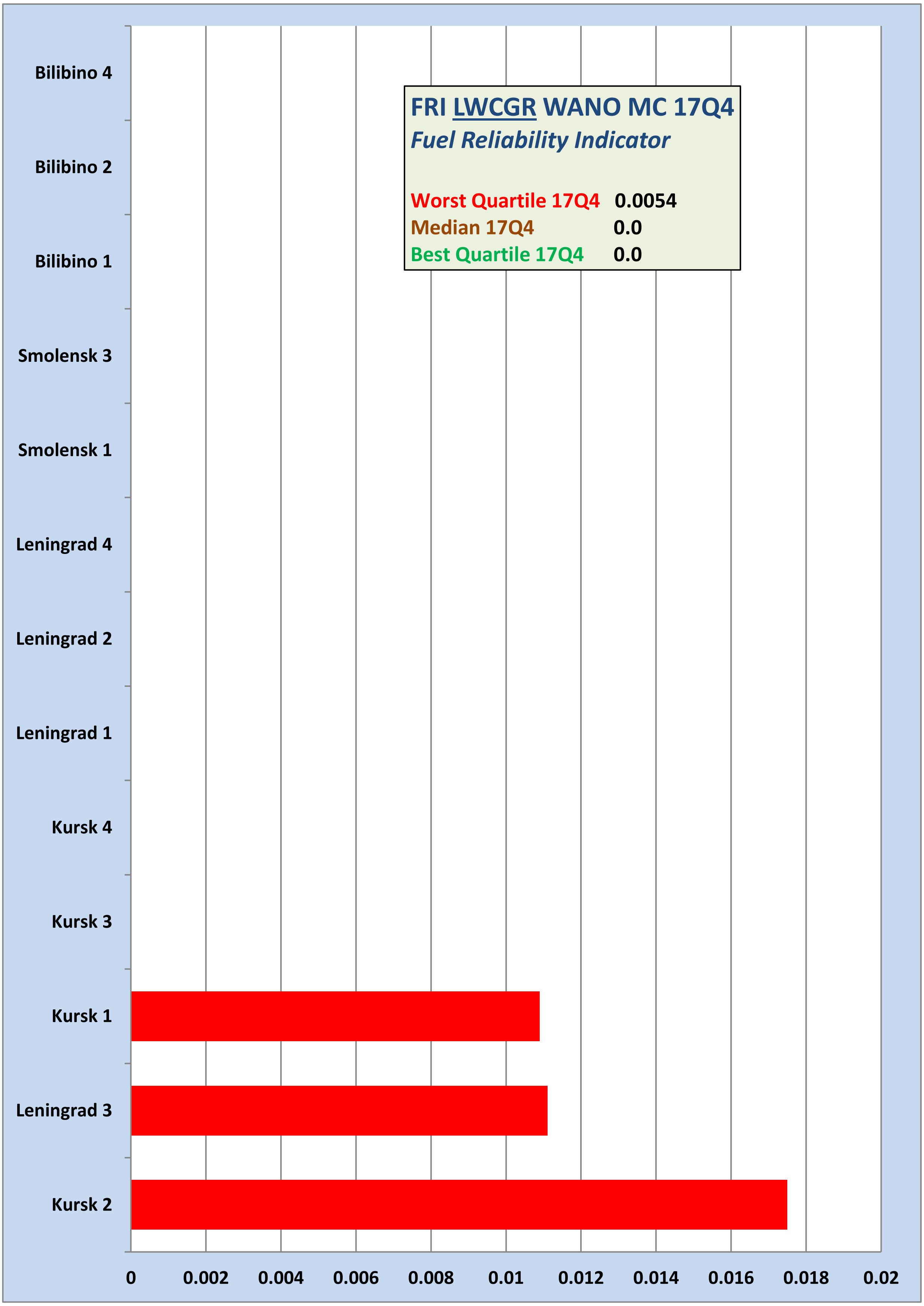
CRE – Collective Radiation Exposure (LWCGR)



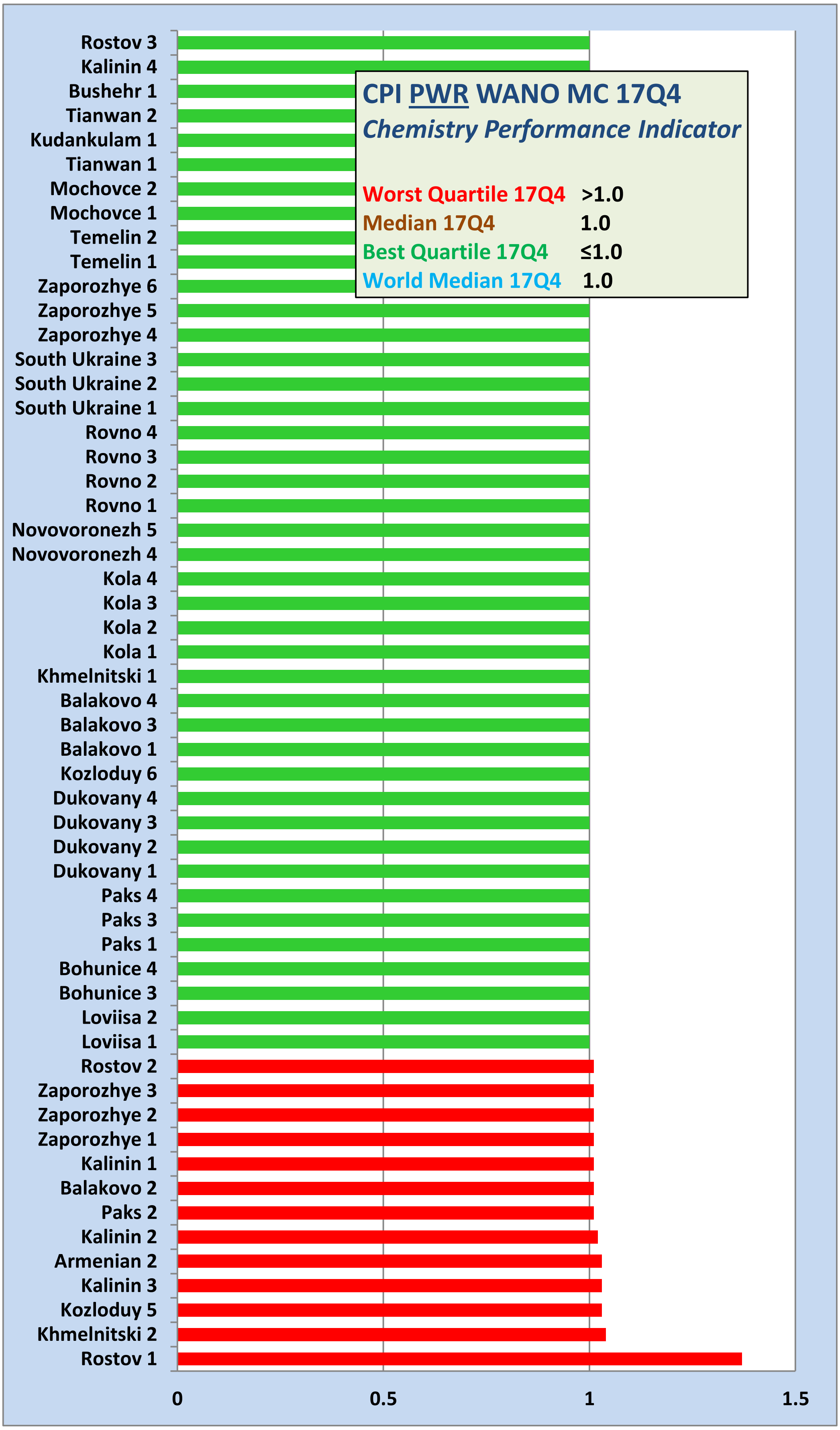
FRI – Fuel Reliability (PWR)



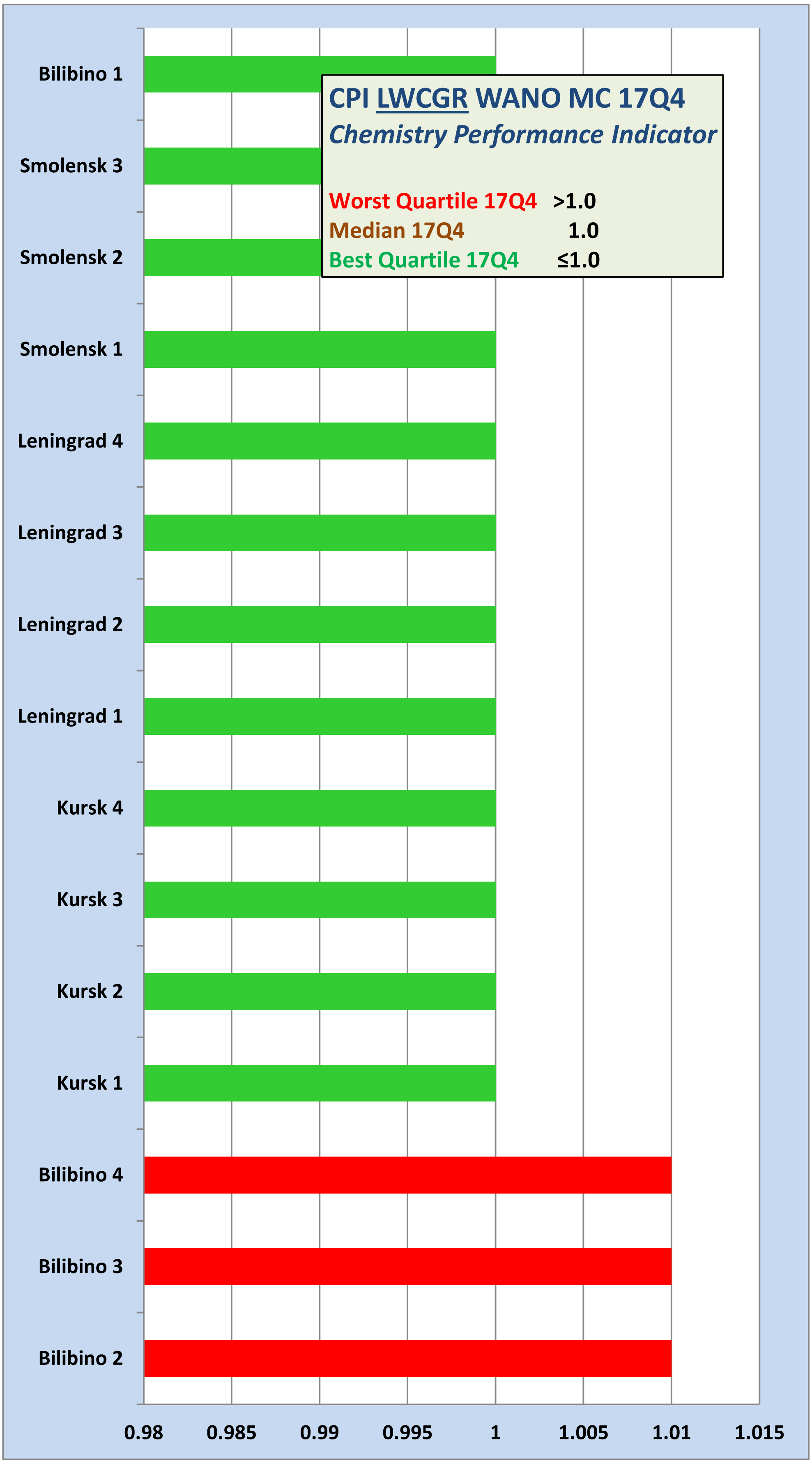
FRI – Fuel Reliability (LWCGR)



CPI – Chemistry Performance (PWR)

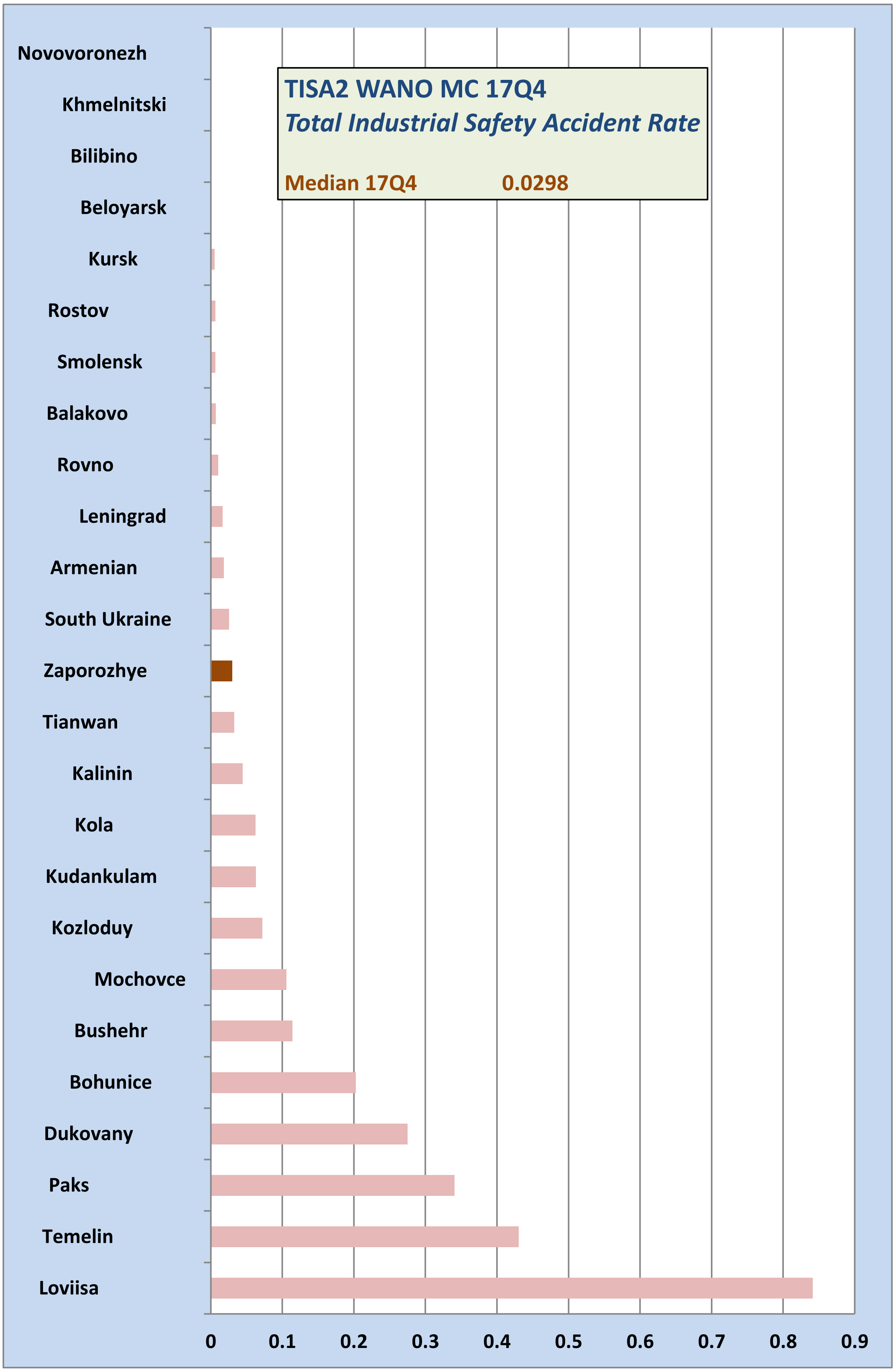


CPI – Chemistry Performance (LWCGR)

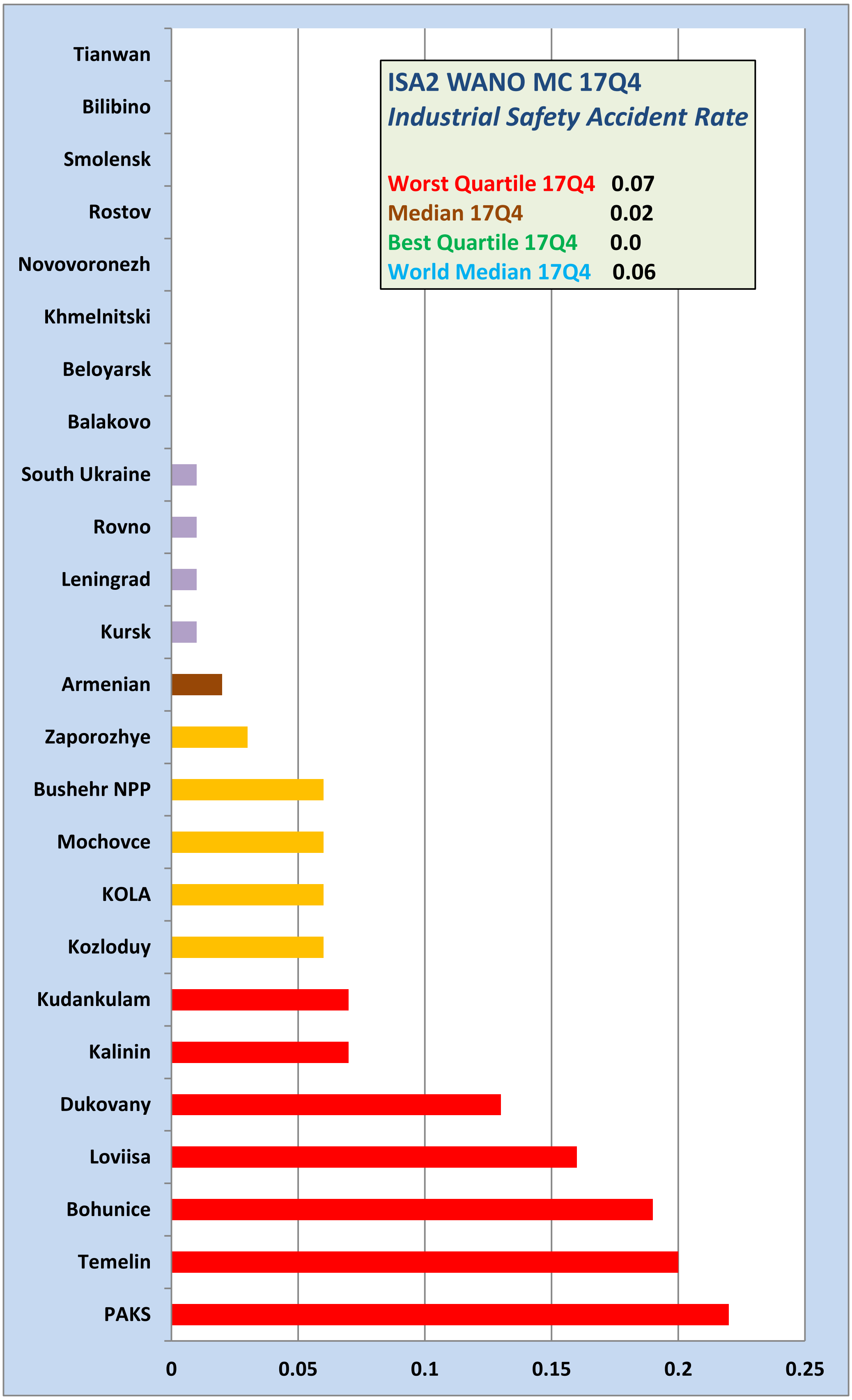


Industrial Safety Indicators

TISA2 – Total Industrial Safety Accident Rate



ISA2 – Industrial Safety Accident Rate for utility personnel assigned to the station



CISA2 – Industrial Safety Accident Rate for contractor personnel