Fuel Assembly Leak Tightness Control on WWER-1000 Reactor

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The main index for integrity of the fuel rods cladding is the specific activity value of the primary coolant. When the reactor is in operation the environment is the primary coolant, and at reactor shut-down the environment is the boric acid solution in the "sipping test" system.

The integrity of the fuel rods cladding is a characterization of the reactor safety. The fuel rod failure index is the fission products specific activity. Their control is the first step to provide safe operation of the WWER-1000 reactor. The fission products are measured at regular time intervals. The gamma-spectrometric control includes:

- Radioactive noble gases – Xe and Kr;
- Iodine isotopes;
- Fission products (FP) – Np, Ba, La, Ce, Sr. The activity of the FP usually is less than the Minimal Detector Activity (MDA).

For WWER-1000, the limit of safe operation for the overall activity of Iodine isotopes (total Iodine) in the primary coolant is $5.0{\cdot}10^{-3}$ Ci/l. These values are corresponding to the maximum number of damaged fuel rods. The limit of normal operation for overall activity of Iodine isotopes (total Iodine) in the primary coolant is $1.0{\cdot}10^{-3}$ Ci/l.

Calculation of the total Iodine is carried out under the following requirements:

- Calculation of the specific activity of Iodine isotopes at nominal parameters – thermal power of 3000 MWt;
- Purification limit 30 t/h and purification factor 10 times more for the purification system.

The maximum and the average activity level of total Iodine in the primary coolant for Kozloduy NPP, Units 5 and 6 for corresponding fuel cycles are presented in Figure 1 (Unit 5) and Figure 2 (Unit 6).

In the whole operation period of the reactors WWER-1000, the normal operation index on total Iodine in the primary coolant, $1.0{\cdot}10^{-3}$ Ci/l, was not achieved and exceeded.

There is another index to characterize the fuel rods (cladding) integrity during reactor operation – the Fuel Reliability Index (FRI). The FRI is defined according to the average activity of ^{131}I in the primary coolant, corrected with a part of the precipitated ^{235}U migration (by average monthly activity of ^{134}I) and fixed to the general permanent purification frequency. The migration of precipitated ^{235}U is originating from the fuel released by damaged fuel assembles (rods) during past fuel cycles, manufacture contamination and precipitates from the reactor internals. Figure 3 presents FRI of the Kozloduy NPP, Units 5 and 6, compared with Worldwide Units Reporting – 243 for 1998. FRI for particular cycles of Units 5 and 6 are presented in Figures 4 and 5.

During refueling, when reactor is shut down, a wet-sipping test is performed. It consists in individual control of each fuel assembly. The nuclear fuel used in the WWER-1000 reactors is manufactured by Russian plants, which provide a list of requirements, according to the specific documentation – technical description of the WWER-1000 reactors.

A procedure to identify radioactivity releases from failed fuel by isolation of an irradiated assembly in a hood, and collection and analysis of the released radionuclides, is used in the wet method.

The principles, structure and design of the can sipping system (CSS) are described below. The system equipment consists of: valve panel, control panel, sipping can, cap, upper and lower support. They are arranged in the fuel storage pool and the sipping control room.

The assembly is placed in a sealed canister CSS and boron solution is being applied twice: for assembly wash and for storage of the assembly under pre-set pressure. After assembly abidance under state conditions, liquid samples are being taken. The cladding integrity control is based on the measurement of liquid samples activity of the isotopes ^{131}I, ^{134}Cs and ^{137}Cs. The level of the assembly stand wash-out from the surface or from the residual contamination is controlled through analysis of ^{54}Mn, ^{58}Co, ^{60}Co, ^{51}Cr and ^{59}Fe corrosion products.

The criteria to determine the fuel rod claddings are:

- Quantitative criteria – ^{131}J activity per assembly shall be less or equal to $1.0{\cdot}10^{-4}$ Ci/l – its value is used to make decision whether to return the assembly to the core or to place it in the fuel storage pool. The assemblies with this activity are assumed to contain fuel rods with failed claddings. According to the technical prescriptions, returning them back for core operation is not allowed;
- Statistical criteria – the activity of each assembly shall be less than the average level of activity plus 3 sigma, where sigma is statistical parameter (standard deviation). Analysis of the statistical distribution of relative activity data of ^{131}I, ^{134}Cs, ^{137}Cs and ^{54}Mn isotopes facilitates the detection of assemblies, containing failed fuel rods. The calculated average activity of isotopes plus 3 sigma is compared to the assembly activity.

The control of the nuclear fuel in conjunction with the fuel rods cladding integrity is carried out in two stages:

- At first, the sipping test of the assemblies to be returned for in-core operation is performed;
- Second, sipping test of the spent fuel assemblies to be placed in fuel storage pool is performed. Figure 6 for Unit 5 and Figure 7 for Unit 6 present the statistical criteria for cladding integrity control.

If the detection of assemblies with ^{131}I leakage is complicated or if more than 28 days passed after reactor shutdown, data for ^{134}Cs, ^{137}Cs activity are being used.

During the operation of Kozloduy NPP, Units 5 and 6, 1474 fuel assembles were verified. No fuel assemblies reached the criterion for taking them out of reactor operation before achieving their full burnup limit. 34 fuel assemblies deviating from the statistical criterion were registered, but most of them were registered after the 1-st cycle of Unit 5 or after achieving the full burnup limit.

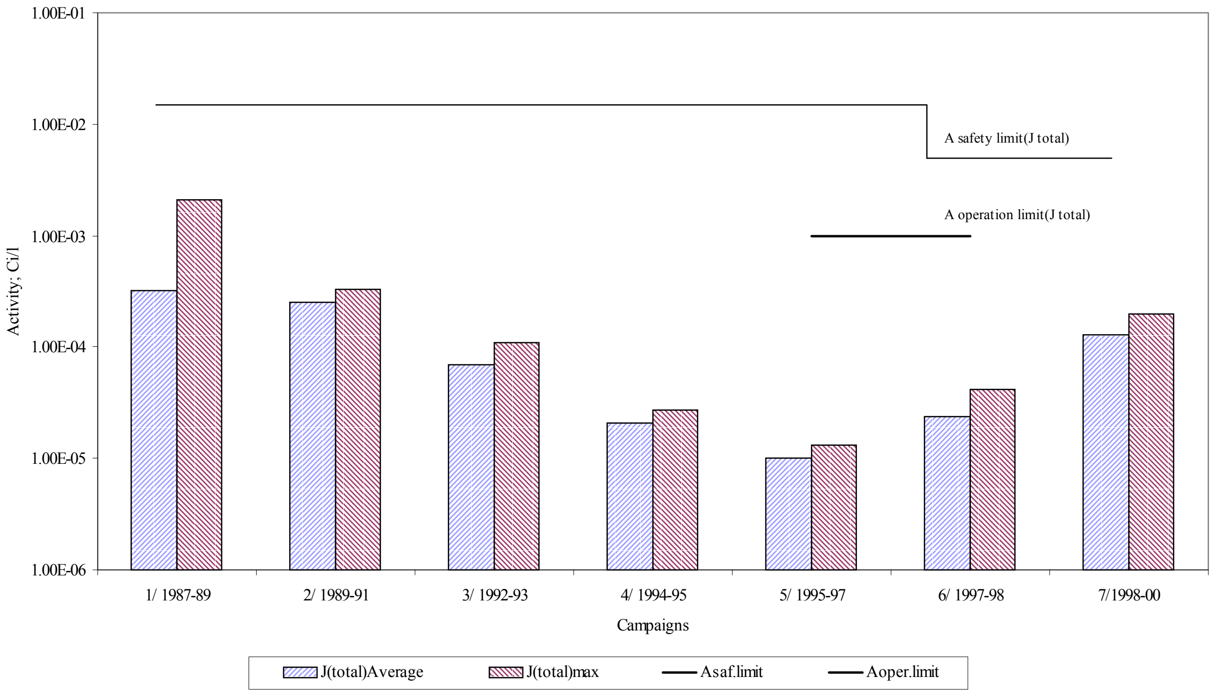

Figure 1. Total activity of I, Kozloduy NPP, Unit 5

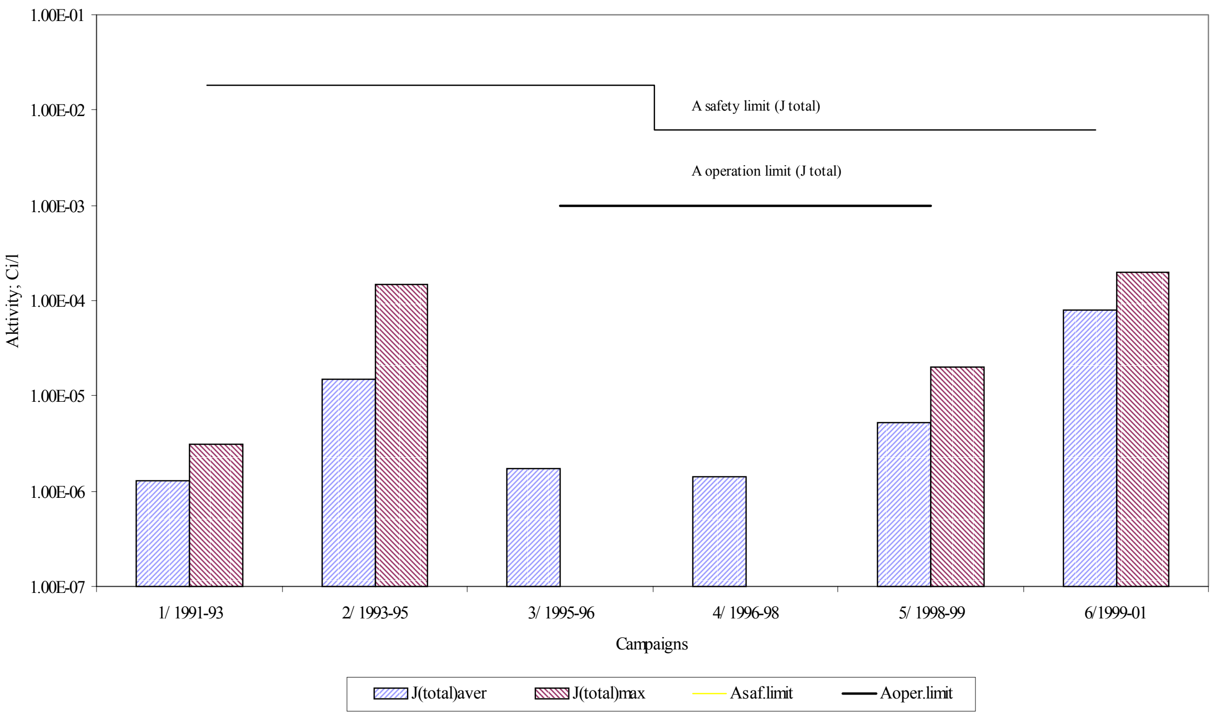

Figure 2. Total activity of I, Kozloduy NPP, Unit 6

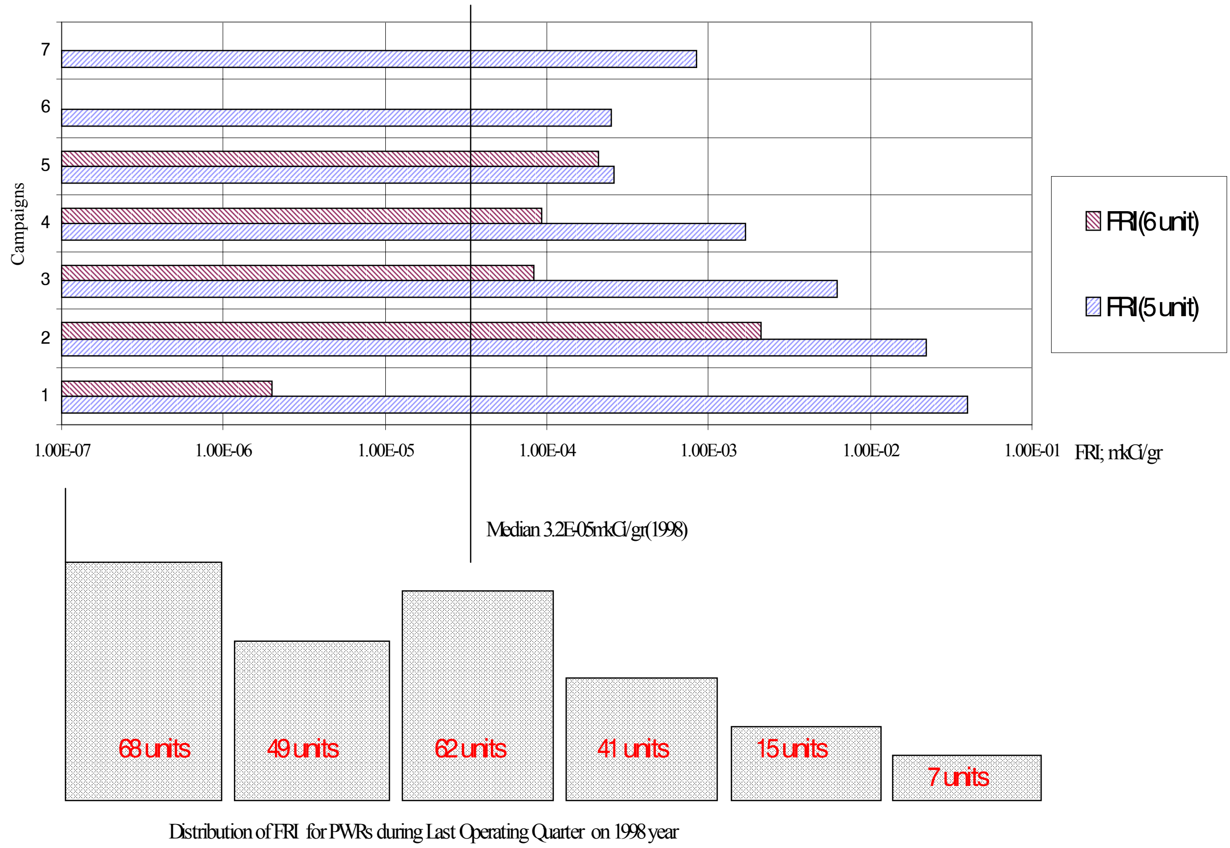

Figure 3. Distribution of FRI

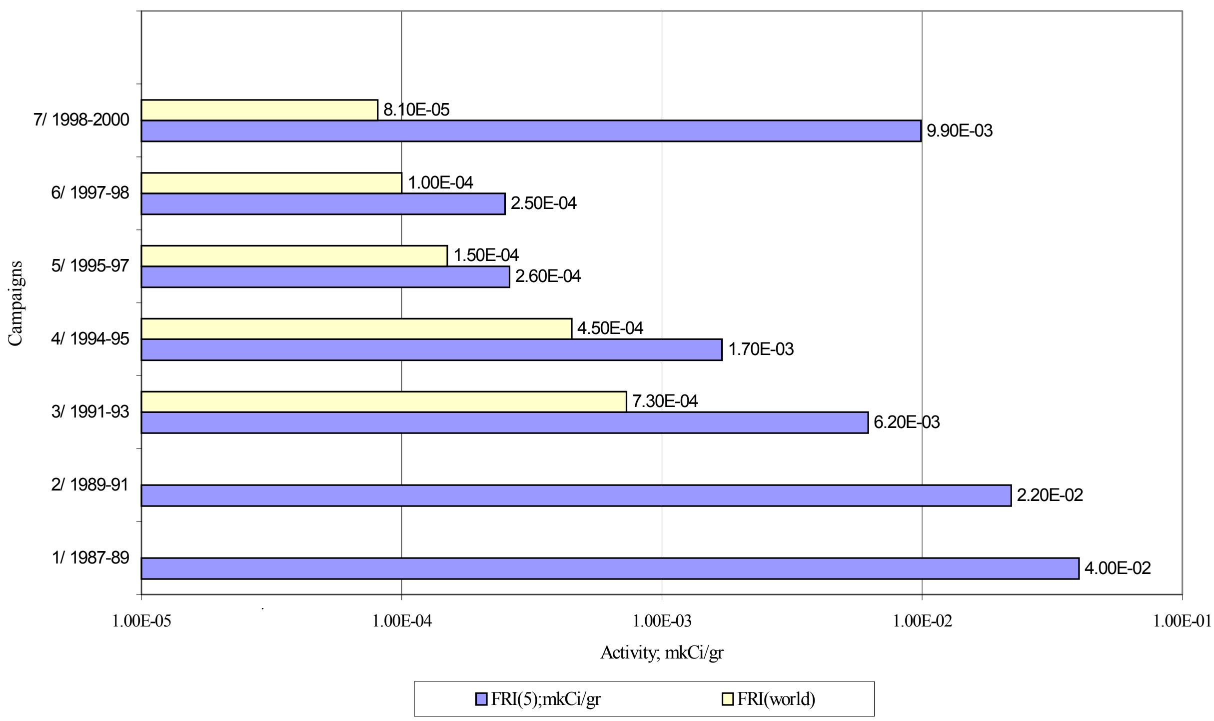

Figure 4. Fuel reliability indicator (FRI), Kozloduy NPP, Unit 5

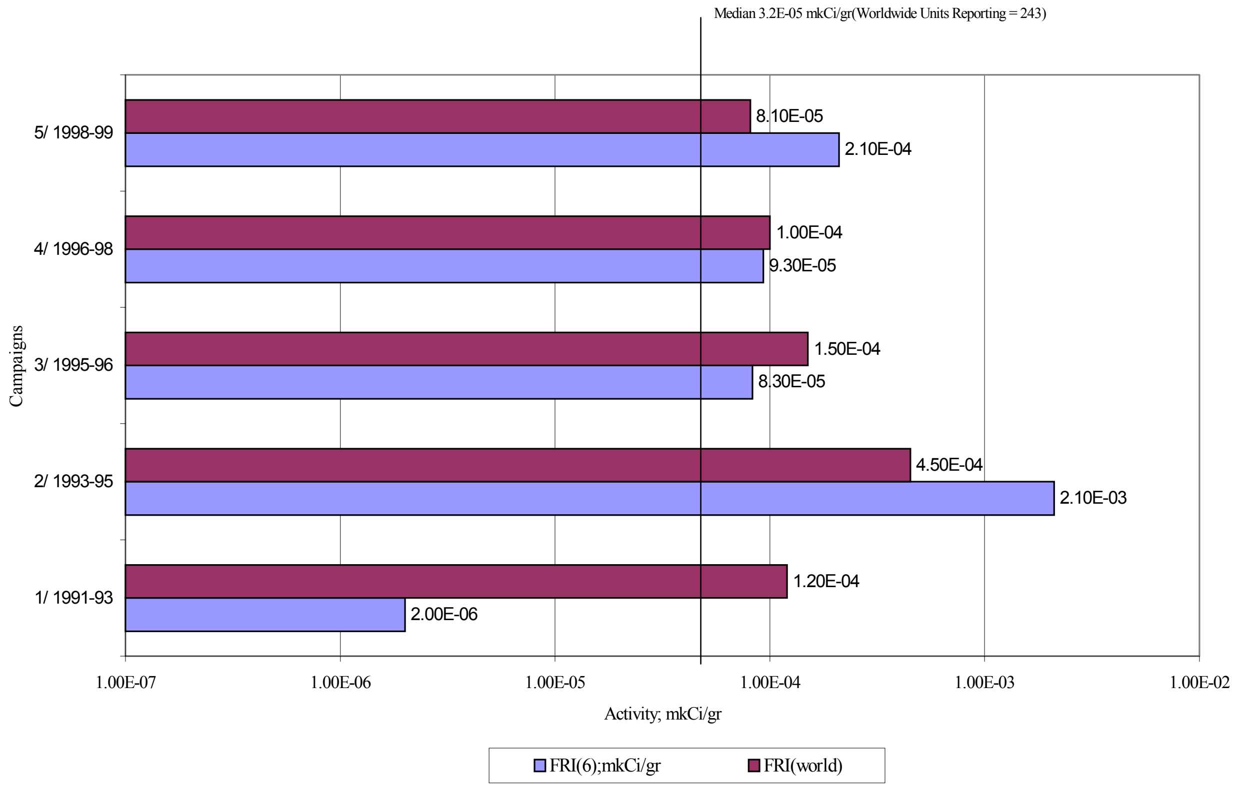

Figure 5. Fuel reliability indicator (FRI), Kozloduy NPP, Unit 6

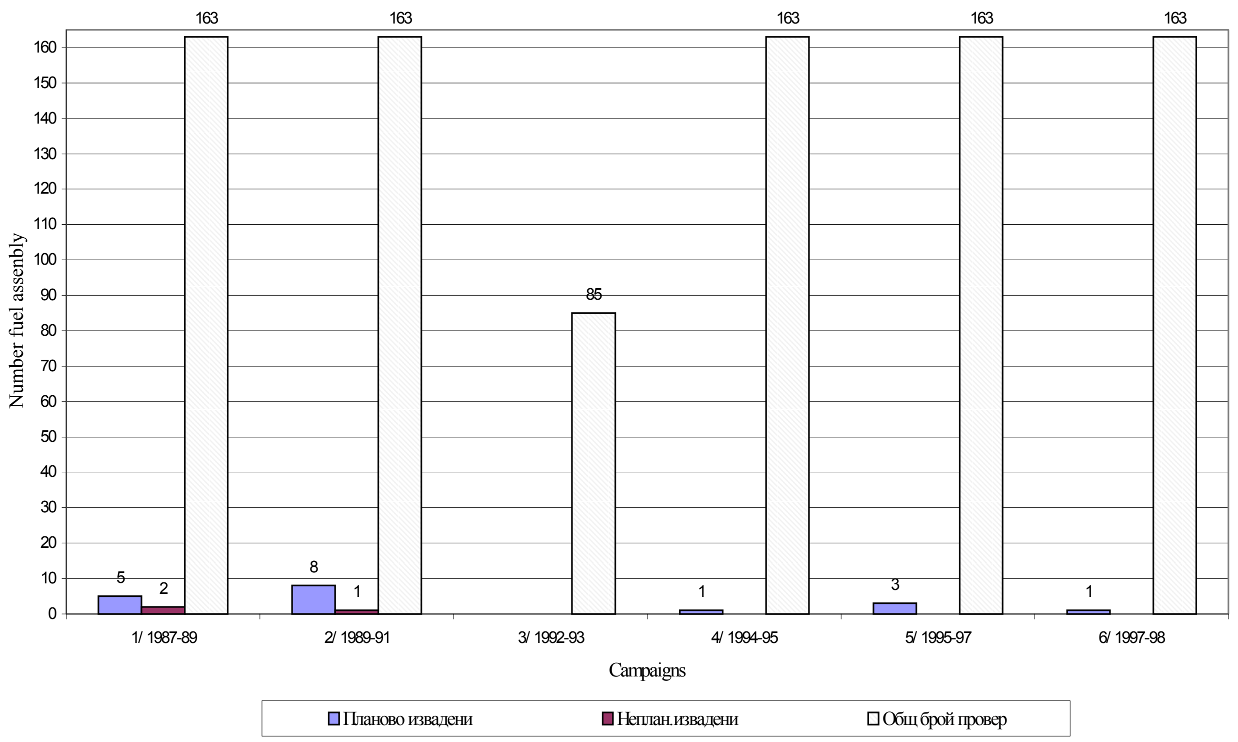

Figure 6. Results from sipping test, Kozloduy NPP, Unit 5

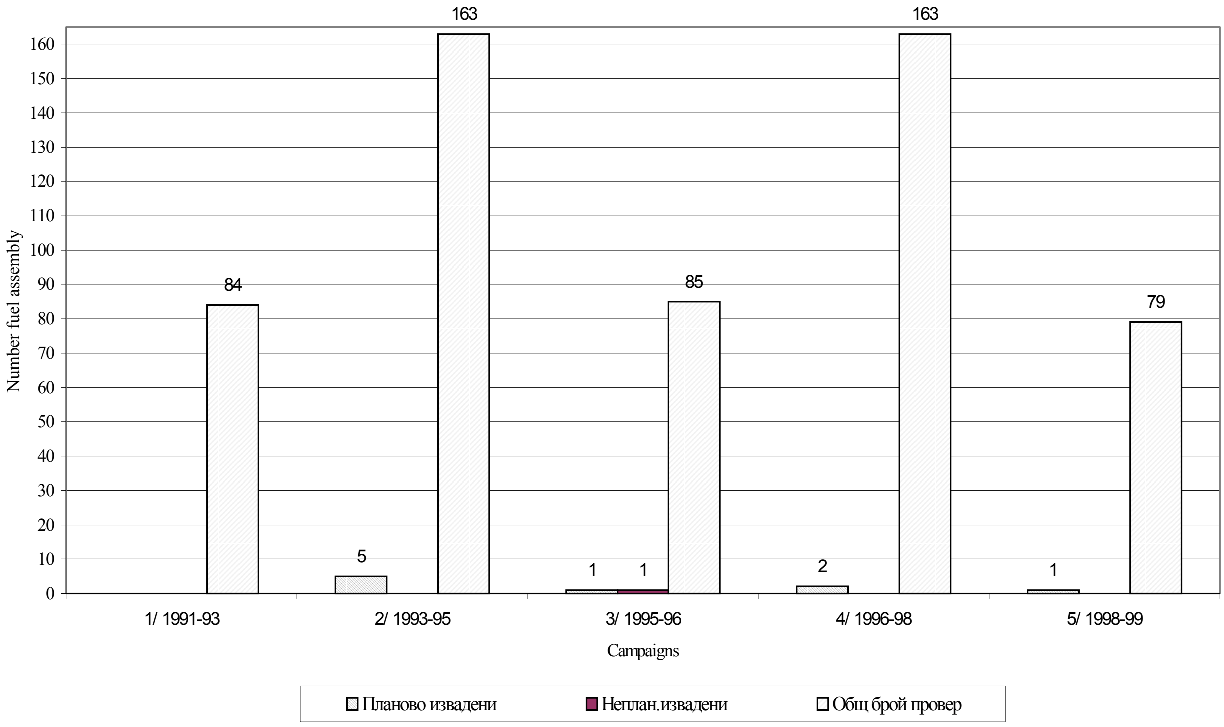

Figure 7. Results from sipping test, Kozloduy NPP, Unit 6