STATUS OF STORAGE AND PREPARATIONS FOR SHIPMENT OF SPENT NUCLEAR FUEL FROM IRT-2000 NUCLEAR RESERCH REACTOR

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ABSTRACT

As a result of 28 years of operation of nuclear research reactor IRT-2000 some amount of spent nuclear fuel has been produced. At this moment 73 spent fuel assemblies are stored in the spent fuel storage pool, albeit without forced circulation.

To solve the problem with the spent nuclear fuel shipping to its country of origin some activities in technical and administrative aspects are carried out.

Visual inspection, dosimetry and gamma-spectrometry measurements have been performed with the aim to establish the physical state, possible corrosion on the cladding and residual activity of the spent nuclear fuel.

Also some corrosion problems occurring due to prolonged non-adequate storage of spent fuel are discussed and a result from X-ray structure analysis and some photo are given in the paper.

1. Introduction

IRT-2000 is a pool type, nuclear research reactor of 2 MW nominal thermal power. It is of Russian design and manufacture and operated from 1961 until July 1989 when it was permanently shut down. As a result on the request of Bulgarian government, an analysis was conducted in 1998 to identify various options for IRT-2000. Accordingly, the Council of Ministers has decided to cease the operation of the IRT reactor and after the site investigation and the environment impact estimation to re-furbish it into a low power reactor which can be used for experimental and training purposes. The power rating is limited on environmental grounds as being consistent with the siting in the suburb of Sofia.

The existing fresh fuel is IRT-2M Russian type fuel with 36% enrichment and is stored at the Kozloduy NPP. Bulgarian government has not yet discussed the problem of reducing the new fuel enrichment according to the requirements of RERTR program.

The spent fuel assemblies (LEU and HEU) are stored on racks in a storage pool. The pool liner is welded with Al sheets. The spent fuel storage pool shows signs of corrosion of the liner and the impact of poor water quality over a long period. The fuel also shows superficial signs of general and pitting corrosion. Three fuel elements especially equipped for temperature measurements have cracks that form large breached areas (about 30 mm) of the clad. The uranium core is directly exposed to the water trough these open areas and shallows corrosion of the uranium surface has occurred.

2. Preparations for shipment

The storage conditions of spent nuclear fuel require to speed up the process of negotiations between Bulgarian and Russian governments for shipment of the fuel. Simultaneously with this some activities about sipping test and canning the damaged fuel, preparation of program and specific fuel data for shipping of the spent fuel must be carried out.

Developing of program

To solve the problem with the spent nuclear fuel shipping to its country of origin it is necessary to meet some technical and administrative requirements.

It is necessary to establish a comprehensive program for technical and administrative preparations required for shipment of spent nuclear fuel which will help to meet the nuclear fuel acceptance criteria. These criteria should be defined on a fuel data base.

To accomplish the government decision a program including the main activities concerning the future of the nuclear research reactor was developed and approved by directorate of the Institute. Accordingly, till 31 January 2000 technical equipment must be chosen and produced for removal of the spent fuel from storage pool and its loading in the transport cask (TK-19). A detailed routing plan will be prepared by a project organization and approved by regulatory body till 30 April 2000.

Nuclear Fuel

The reactor operation had produced a relatively small number of spent fuel assemblies of both LEU (57 fuel assemblies 10% enriched) and HEU (16 fuel assemblies 36% enriched) fuel. The reactor core was loaded with mixed LEU and HEU fuel from 1985 till 1989.

The original EK-10 fuel with 10% enrichment is uranium dioxide dispersed in magnesium and C-36 fuel with 36% enrichment is uranium-aluminum alloy. Both were made up of rods arranged in aluminum assembly. The fuel rods have aluminum alloy cladding. The rods held at both ends in aluminum grids are fastened to the assembly (Fig. 1).

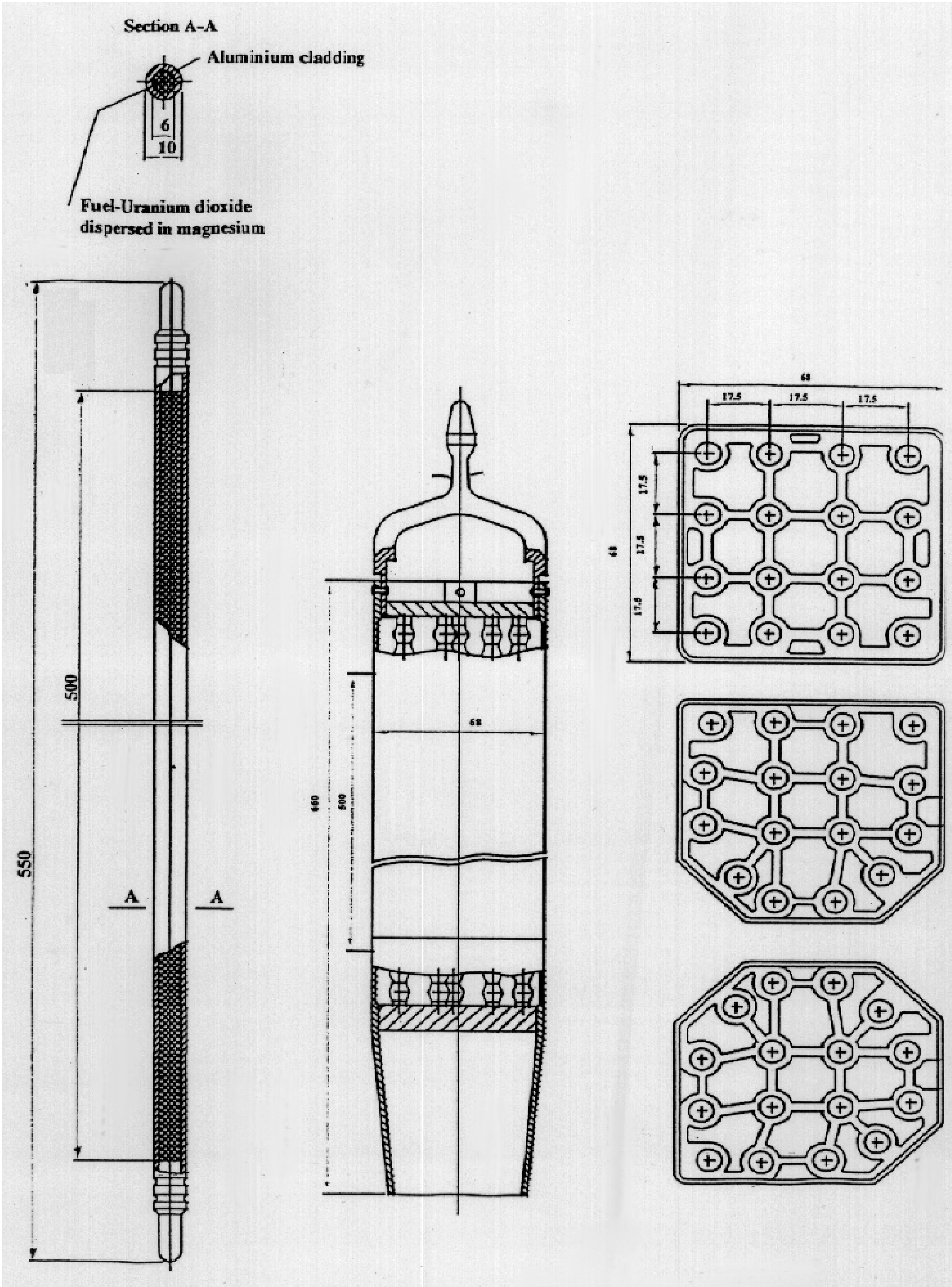


Figure 1. Fuel rod and fuel assembly

Data Preparation

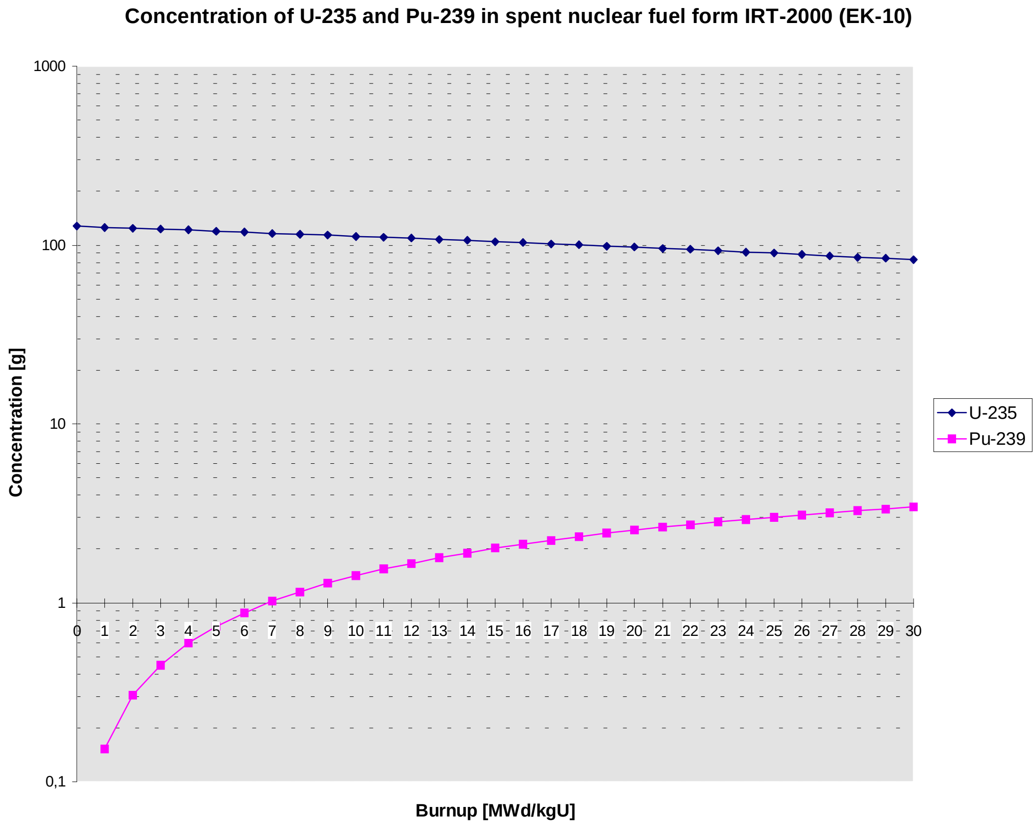
The fuel assemblies to be shipped from reactor facility must be selected and classified. The selection and classification depends on the specific fuel element data.

Preparation of data for the spent nuclear fuel concerning fuel irradiation history; burn up of U-235; accumulation of fission products as U and Pu; maximal burnup; cooling time; fuel residual activity and fuel dose rate is important for determination of the spent nuclear fuel acceptance criteria.

In order to ensure the validity of fuel data two types of calculations have been performed:

- calculations based on irradiation fuel history data, produced energy and final burnup ;
- calculations based on modeling of U-235 burnup and accumulation of fission products U-236, U-238, Pu-239, Pu-240, Pu-241 and Pu-242 by the licensed computer code NESSEL-4 [1].

Fig. 2 shows the U-235 burnup and the production of Pu-239 in an IRT-2000 fuel assembly containing UO_2+Mg with 10% U-235 enrichment.



Results for the U-235 content, the sum of uranium and plutonium isotopes, obtained in the two types of calculations are presented in Table 1 and Fig. 3. The analysis of these calculations shows good coincidence between the calculated and modeled quantities. The differences in the isotope's content are due to the procedure used in calculations and the computer modeling - in the first case the assemblies final burnup is based on the real produced energy, while in the second case are used "burnup steps", required by the computer code used.

Table 1: Calculated and modelled U-235 content and sum of uranium and plutonium isotopes

Burn up [%]	Calculated U-235 content [g]	Modelled U-235 content [g]	Differences between calc. and modelled U-235 content [%]	Calculated U+Pu content [g]	Modelled U+Pu content [g]	Differences between calc. and modelled U-235 content [%]
11	111.41	110.70	0.64	1265.82	1240.09	2.08
13	107.72	107.70	0.01	1262.67	1237.46	2.04
15	104.05	104.73	0.65	1259.53	1234.78	2.00
16	102.40	103.25	0.82	1258.12	1233.55	1.99
19	97.86	98.79	0.94	1254.24	1229.61	2.00
20	93.29	95.82	2.64	1250.04	1226.99	1.88
21	94.83	95.82	1.03	1251.65	1226.99	2.00
22	93.79	94.45	0.70	1250.76	1225.74	2.04
23	91.13	92.97	1.98	1248.49	1224.49	1.96
24	89.52	91.48	2.14	1247.11	1223.14	1.96
25	88.37	89.99	1.81	1246.13	1221.77	1.99
26	87.53	88.63	1.24	1245.41	1220.54	2.04
27	85.14	87.14	2.30	1243.37	1219.25	1.98
28	84.28	85.69	1.65	1242.63	1217.92	2.03
30	81.26	82.80	1.86	1240.05	1215.23	2.04

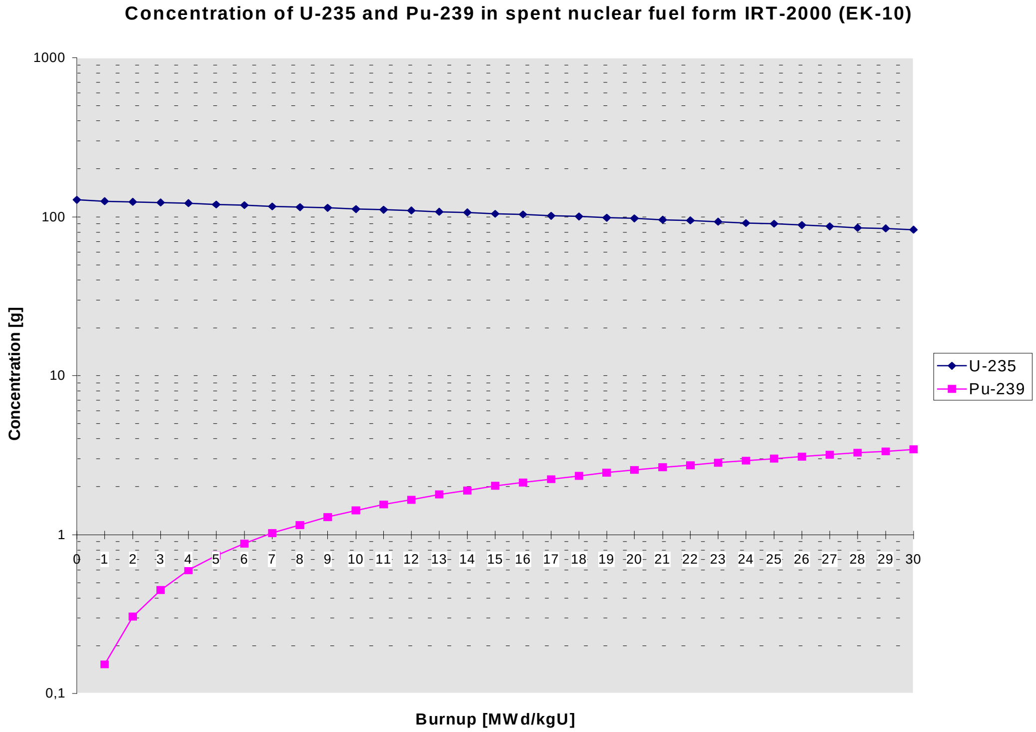


Fig. 2

3. Status of storage

The used fuel from the IRT-2000 reactor is currently safely stored in a pool, albeit without forced circulation. The original storage strategy was to store fuel elements pending their return to Russia. A return of the fuel to Russia is still considered the best option.

Storage facility

Spent fuel assemblies are stored in racks in a separate storage pool, containing about 12 m^3 of deionized water, connected with the reactor pool by an inclined channel for refueling operations. The pool of depth 5770 mm, width 1010 mm and length 1910 mm is lined with 6-mm thick aluminum. The storage capacity was increased in 1988 by installing additional racks on two levels. Criticality calculations were performed to show that the geometry (pitch between storage channels is 190x170 mm) would allow storage of up to 112 C-36 spent fuel assemblies. The upper racks have IAEA safeguards seals attached to prevent disturbance of fuel stored in the lower racks.

Water chemistry regime

To prevent a fuel against corrosion a proper water chemistry regime have to be maintain in the spent fuel storage pool. Water quality in storage pool is measured monthly and the controlled parameters are:

- water level – continuously (light and audio signals);
- visibility – weekly;
- electrical conductivity, chemical composition, pH, dry and heated residue and concentration of aggressive ions – all monthly.

The chemical composition is determined by gamma-spectrometry and the other parameters by chemical methods.

To quantify the concentration of aggressive ions in the water that may speed up the process of corrosion, the required measurements have been performed using atomic emission spectroscopy with inductively coupled plasma (AES-ICP).

The local limits for pH, conductivity, concentration of aggressive ions and activity levels for the spent fuel storage pool, compared with measured parameters in other countries, are given in Table 2. The higher local limits are chosen due to the fact that the water in the spent fuel storage pool is not re-circulated and purified and it is difficult to maintain lower limits for conductivity and aggressive ion concentration. Comparison of the results with other countries shows a relatively good quality of the storage pool water.

To enhance the water quality in the storage pool a water treatment plant with deionization equipment needs to be used. Using a portable deionization equipment at Savannah River Site K-Basin Reactor the water conductivity was reduced from 175µS/cm by early 1995 to 1.8µS/cm by March 1996 [2].

Table 2: Limits for pH, conductivity, concentration of aggressive ions and activity level in the spent nuclear fuel storage pool.

Measured parameter	Local limiting values	Measured values IRT-Sofia	Measured values RR in Germany [5]	Measured values SRS K-Basin before 1995 [4]	Measured values JAERI-RR [6]
pH	5.0 ÷6.5	6.03 ÷ 6.14	5.5 6.5	7.5	5.8
Conductivity	≤ 10 µSm/cm	2.50 ÷ 3.34 µSm/cm	≤ 1 µSm/cm	175 µSm/cm	0.9 ÷ 1.2 µSm/cm
Dry residue	≤ 10 ppm	3.0 ÷ 4.4 ppm			
Heated residue	≤ 3 ppm	2.2 ÷ 3.0 ppm			
Content of Fe	≤ 0.1 ppm	≤ 0.01 ppm	≤ 0.001 ppm		
Content of Al	≤ 0.1 ppm	≤ 0.01 ppm			
Content of Cl	≤ 0.1 ppm	≤ 2.2 ppm	≤ 0.1 ppm	18 ppm	
Content of Cu	≤ 0.1 ppm	≤ 0.01 ppm	≤ 0.001 ppm		
Content of Co	≤ 0.1 ppm	≤ 0.02 ppm			
Content of Ni	≤ 0.1 ppm	≤ 0.02 ppm	≤ 0.001 ppm		
Gamma-spectr. Analysis Cs-137 Co-60	 ≤ 400 Bq/dm^3 ≤ 100 Bq/dm^3	 29.2 Bq/dm^3 29.8 Bq/dm^3			

Performance of containment barriers

The main containment barrier is the fuel clad. To establish the physical conditions of the fuel rods and claddings visual inspections for possible corrosion on the fuel surface and fuel rod deformation are carried out using the hot cell of the radiochemistry laboratory. The hot cell is arranged with backlighting so that the viewer could see along the rods. Each year eight fuel assemblies are inspected and every five years a full inspection of all the fuel assemblies is carried out. The inspections are performed under very difficult optical conditions, i.e. through lead glass and with a sodium lamp, and the extent of the corrosion is difficult to quantify.

Fuel corrosion and fuel deformation

The results from the last visual inspection, carried out from 1 of March to 30 of July 1999 show that some fuel rods are badly bowed and several are covered with nodular deposits, which most probably indicates underlying pitting corrosion. Four fuel elements have bubbles positioned under aluminum cladding.

Summarized results concerning fuel corrosion and fuel deformation for different fuel enrichment, lifetime and cooling time are shown in Fig. 4 and Fig. 5.

The last visual inspection of the spent fuel clarifies that 31.5% of all fuel rods have not got any corrosion; 28.9% have only 5% surface pitting corrosion; and for 5.2% of fuel rods ~100% of clad surface is covered by pitting formations.

Concerning the fuel rods deformation – 48.8% of all rods are without any deformations, for 45% weak deformations have occurred and 6.2% of all fuel rods are badly bowed.

Problems with fuel integrity

In the earlier period of operation of IRT-2000, 6 fuel rods had been equipped with thermocouples to measure the temperature in reactor core. Few shallow grooves were made in the fuel cladding (1 – 1.5 µm depth) in which were placed the wires of the thermocouples. During the long term of storage these grooves have opened and formed areas in which the fuel core is directly exposed to the water. As a result, a shallow corrosion of uranium surface has occurred, causing a swelling of its volume.

The lower dose rate (approximately 25 mrem/h at 1-m air) allowed us to drag these elements out of the water and to take a good photo (Fig. 6). The smears taken from the cracks show presence of U-235, Cs-137 and Co-60.

The careful view of the cracks shows corrosion formations along the grooves, which may be due to galvanic corrosion. Galvanic corrosion occurs when a metal or alloy is electrically coupled to another metal (Al cladding and Cu wires) in the same electrolyte.

A corrosion formation was occurred also at the top of the fuel element. A X-ray analysis of the sample taken from this corrosion formation (performed at Laboratory for Geological Investigations) shows presence of less than 1% of Boehmite (Al_2O_3) and 99% aluminum hydroxide - $Al(OH)_3$. This result indicates presence of sufficient corrosion on the aluminum cladding of these fuel elements.

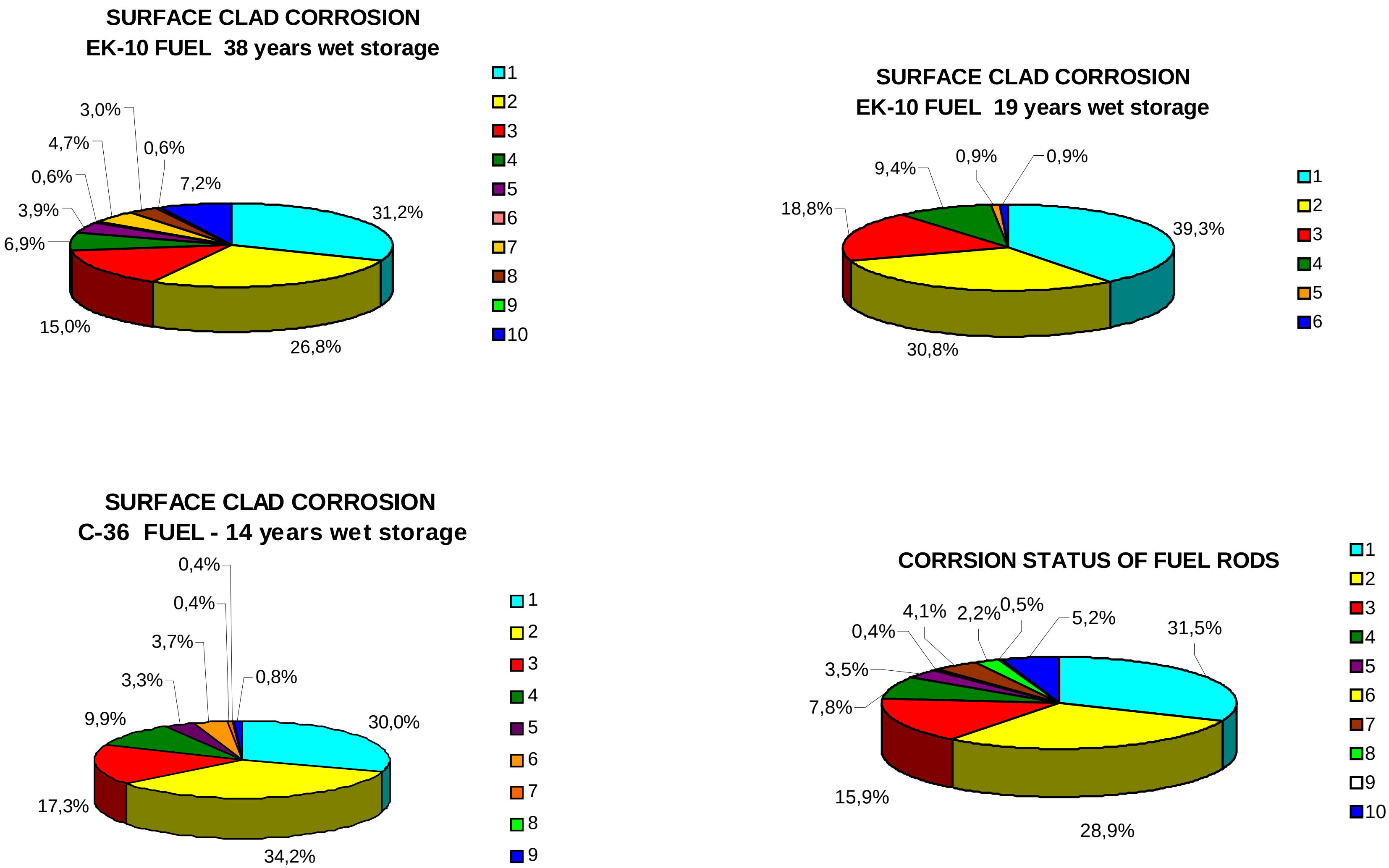


Fig. 4 Corrosion Status of the Fuel Rods

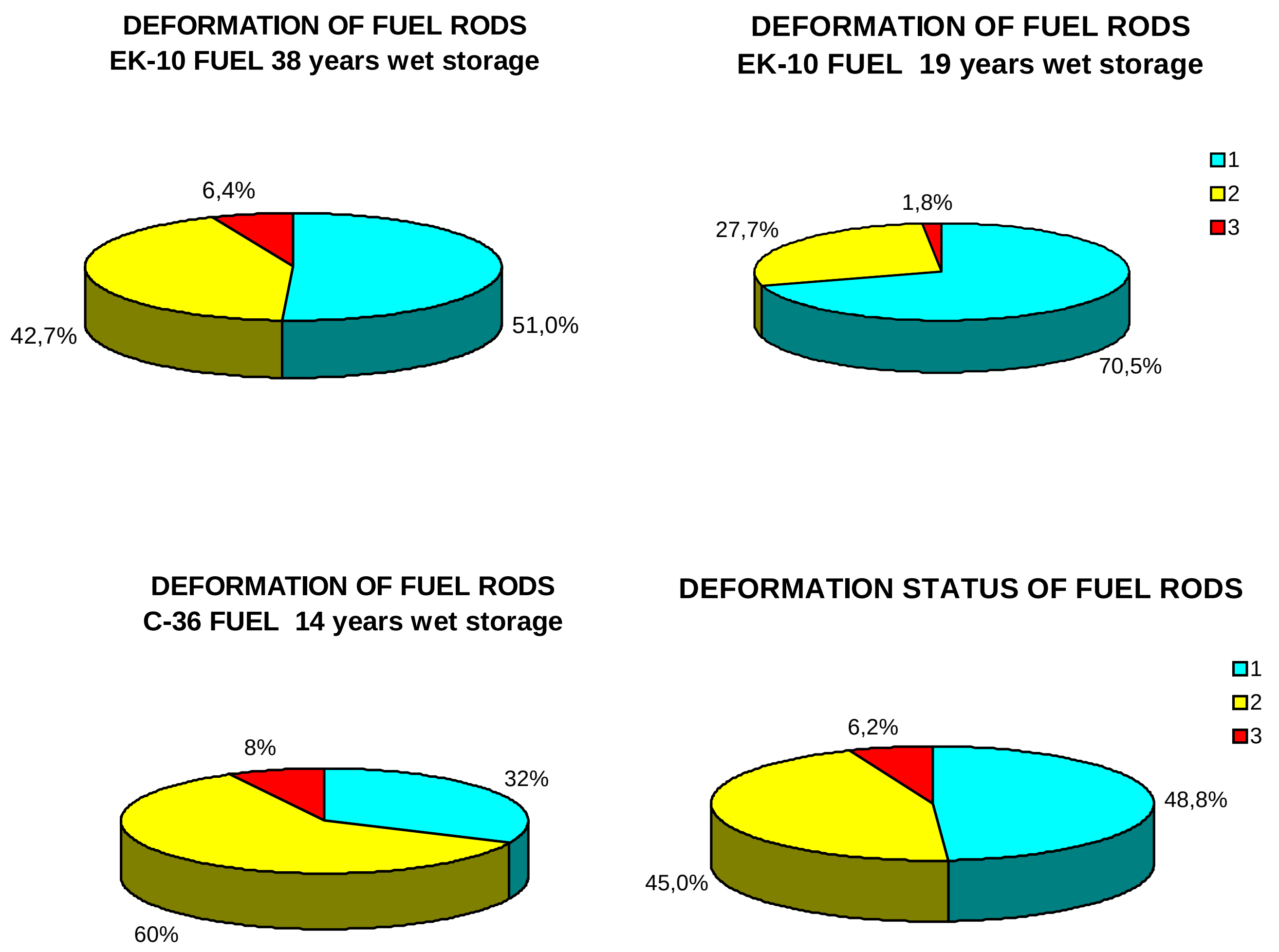


Fig. 5 Deformation Status of the Fuel Rods

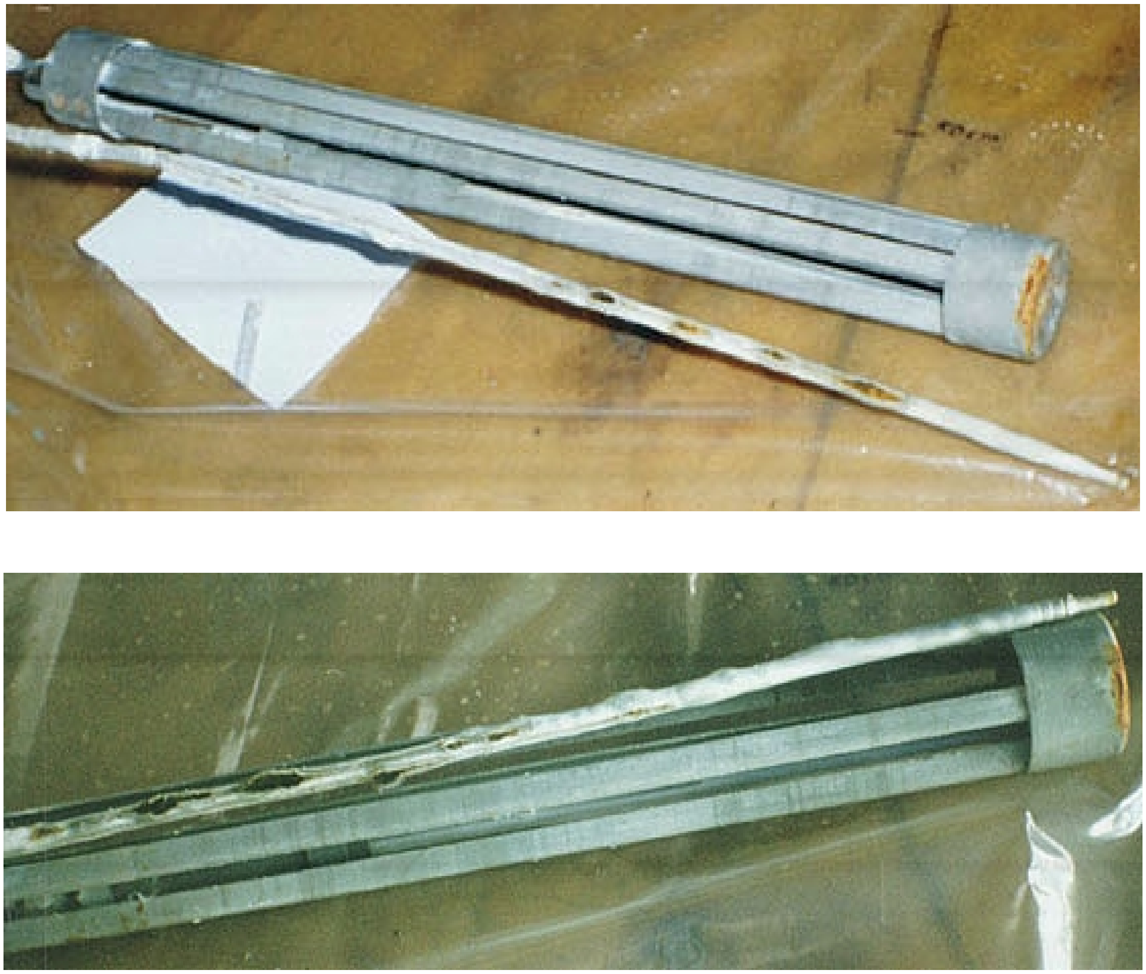


Fig. 6 Corroded Fuel Rods That Were Equipped With Thermocouples.

4. Conclusions

To ship the IRT-2000 spent nuclear fuel to its country of origin in a safe manner the following activities must be carried out:

1. To speed up the process of negotiations between Bulgarian and Russian governments for shipment of the fuel
2. To develop a program for spent fuel management and its preparation for shipment.
3. To perform the sipping test of the spent nuclear fuel to declare its tightness.
4. To can the non-intact fuel that may have leakage.
5. To improve the water quality using a purification system to prevent the nuclear fuel against rapid corrosion.

Acknowledgements:

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