Back End strategy in Bulgaria: Interfaces related issues and potential solutions

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## KNPP: Overview

<table>
<thead>
<tr>
<th>Unit</th>
<th>Type</th>
<th>Year of commissioning</th>
<th>Current status</th>
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<tbody>
<tr>
<td>5</td>
<td>WWER-1000/B-320</td>
<td>1988</td>
<td>In operation, 25-th fuel cycle</td>
</tr>
<tr>
<td>6</td>
<td>WWER-1000/B-320</td>
<td>1991</td>
<td>In operation, 23-th fuel cycle</td>
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</table>
The WWER-440 units 1-4 are currently under the decommissioning stage.

Nuclear Fuel Department (Section Reactor-physics Calculations) is involved in one of the most important tasks – Induced activity and dose rates calculations of the structures, components and materials into and surrounding the reactor core.

The WWER-1000 units are operational and the program for modernization and overhauling of Unit 5 was completed and it had received operation license for a period of 10 years (the maximum allowed by the Bulgarian legislation).

Currently Unit 6 is undergoing the same process. It is expected that this will prolong the operational lifetime of the units for another 30 years (up to 2047 for Unit 5 and up to 2051 for Unit 6 respectively).

In November 2016 the newly licensed fuel TVSA-12 was loaded in the core of Unit 6. Using this fuel assemblies (based on the design of TVSA fuel assemblies) will reduce the generated spent nuclear fuel by up to 10% annually.
NFC Management Structure of KNPP

Production Director

Chief Engineer
Electricity Production

Head of Engineering Division

Reactor-physics
technology Section

Head of Operation Division

Nuclear Fuel Department

Spent Fuel Storage Department

Nuclear Fuel Cycle Section

Reactor-physics calculations Section
**NFC Management Structure of KNPP**

At KNPP, Nuclear Fuel Department and Reactor-physics technology Section are in different divisions. The idea is to ensure a mutual check-up of the refueling pattern.

**The main tasks of Nuclear fuel Department are:**

- **NFC Section** is concerned manly with quality and delivery (contracts, permits, licenses, etc.) of the fresh fuel for KNPP and the transportation of both the FNF and SNF and the reprocessing of the latter.

- **Reactor-physics Calculation section** works in the field of neutron-physics characteristics calculations; core design and reloading calculations; fuel cycles optimizations; residual heat and activity calculations (for example spent fuel assemblies, activity distribution in stainless steel components: protective tube unit, baffle and barrel).

- **The main tasks of Reactor-physics technology (RPT) Section** are fuel loading fresh and spent fuel in-site movement, nuclear safety surveillance, reactivity control during the start-up physics tests at HZP states, at power increasing and decreasing states, in-core monitoring system surveillance, Smartfuel database maintenance.

- **Both sections, NFC and RPT observe** (as a part of the QA Program) the manufacturing process of fresh fuel assemblies at the manufacturer plant in Russian Federation.
**Fuel assemblies for WWER-440**

**Fuel assembly (PK)**
- The fuel assembly is a fixed structure and consists of a bundle of 126 rods, spacer grids, top grid, support grid, central tube, basket pipe, top and bottom nozzle.
- The top and the bottom nozzle have a wrench size 144 mm. The total length of the FA is 3217 mm. The assembly contains a total of about 120 kg of heavy metal. The fuel assemblies are manufactured with enrichment of 1.6%, 2.4% and 3.6% and are labelled with codes 116, 124 and 136 respectively.

**Control assembly (APK )**
- In principle, it does not differ from the PK assembly. The differences are as follows:
  - the fuel pile is 10 cm shorter, resulting in a heavy metal content of 115 kg;
  - in the top there is a bayonet grip with locking mechanism;
  - there is a mechanism in the bottom nozzle that slides over the dampener of the casing pipe in the core bottom and softens the impact;
- Dimensions across flats ‘wrench size’ of the top and bottom nozzle is 145 mm.
- Control assemblies are manufactured with enrichment of 1.6%, 2.4% and 3.6% and are labelled with codes 116, 124 and 136 respectively.
The accumulated spent nuclear fuel at the site of Kozloduy NPP, stored in SFP (reactor pools) and SNFSF, as of 12.31.2017 totals 884 tHM. This quantity is distributed in 2864 WWER-440 spent fuel assemblies and 1371 WWER-1000 spent fuel assemblies, sum total of 4235 assemblies.

Type of SF in SNFSFs as of 12.31.2017 are presented on the next slides:
**TBC fuel assembly**

*for 2-year cycle*

- The assembly has a steel frame and is a fixed structure. It consists of a top nozzle with a spring block, a central tube, 18 guide tubes, 15 spacer grids, 312 fuel rods and bottom nozzle.

- The shape of the assemblies used is hexagonal, with dimensions across flats ‘wrench size’ of 234 mm. The total length of the assembly is 4570 mm. Assemblies are manufactured with enrichment of 1.6%, 2.0%, 3.0%, 3.23% and 3.3% and are identified by the following indexes: Н, А, В, ГВ, Г. At KNPP are used assemblies with enrichment of 2.0%, 3.0%, 3.23% and 3.3%. Fuel rods are filled with UO₂ fuel pellets with central hole. The assembly as fresh fuel contains the total of 429.7 kg heavy metal.
Fuel assemblies for **WWER-1000**

**TBC-M fuel assembly**
for 3-year cycle

- The assembly has a steel frame and is dismountable structure. It consists of a top nozzle with a spring block, a central tube, 18 guide tubes, 15 spacer grids, 312 fuel rods and a bottom nozzle.

- The shape of the assemblies used is hexagonal, with dimension across flats ‘wrench size’ of 234 mm. The total length of the assembly is 4570 mm. Assemblies are manufactured with enrichment of 1.6%, 3.0%, 3.6%, 4.23% and 4.40% and are identified by the following codes: Н, В, Д, ЕД, Е. At KNPP assemblies with enrichment of 3.0%, 4.23% and 4.4% are used. Fuel rods are filled with UO₂ fuel pellets with central hole. The assembly as fresh fuel contains the total of 399.9 kg of heavy metal.
**Fuel assemblies for WWER-1000**

**TBCA fuel assembly**

used in the current 4-year cycle

- The assembly has a steel frame and is a dismountable structure. It consists of top nozzle with a spring block, a central tube, 18 guide tubes, 15 spacer grids, 312 fuel rods, 6 of which with 5% Gd$_2$O$_3$ burnable absorber and bottom nozzle.

- The shape of the assemblies used is hexagonal, with dimension across flats ‘wrench size’ of 235 mm. The total length of the assembly is 4570 mm. Assemblies are manufactured with enrichment of 1.3%, 2.2%, 3.53%, 3.90%, 3.99%, 4.30% and 4.38% and are respectively labelled with indexes N1300, N2200, N3536, N3906, N3996, N3996, N4306 and N4386. At KNPP fuel assemblies with indexes N3536, N3996 and N4306 are being used. The assembly is manufactured with UO$_2$ pellets with a central hole. The assembly as fresh fuel contains the total of ~433.4 kg heavy metal.
**TBCA-12 fuel assembly**

*used in the current 4-year cycle*

- The assembly has a steel frame and is dismountable structure. It consists of a top nozzle with a spring block, a central tube, a central tube, 18 guide tubes, 12 spacer grids, 312 fuel rods and bottom nozzle, 6 or 12 of which with Gd$_2$O$_3$ burnable absorber.

- The shape of the assemblies used is hexagonal, with dimension across flats ‘wrench size’ of 235 mm. The total length of the assembly is 4570 mm. Assemblies are manufactured with enrichment of 3.97%, 4.31%, 4.6% and 4.62% and are respectively labelled with indexes N39712, N43106, N46012 and N46206. The assembly is manufactured with UO$_2$ pellets without a central hole (the fuel rods with absorber have pellets with a central hole). Fresh fuel assembly contains the total amount of 481.8 kg heavy metal.
**KNPP: Reactor pools**

**RP of Unit 5 and Unit 6**

- Full capacity of Unit 5 pool is **612 fuel assemblies** (at least 163 have to be free when the reactor is operational).
- Full capacity of Unit 6 pool is **611 fuel assemblies** (at least 163 have to be free when the reactor is operational).
- The nuclear Safety is ensured by the designed assembly pitch.
- The cooling system has to maintain the water temperature <**50°C**.
Wet Storage Facility (WSF) – for the WWER-440 and WWER-1000 SNF – commissioned 1990.

- Full WSF capacity is **160 baskets** (152 can be used for baskets with SNF WWER-1000).
- The baskets with the SNF are stored in chemically desalted water.
- Each WWER-440 basket contains up to 30 FA with maximum allowed residual heat **15 kW** and activity **1.73×10^{17} Bq**.
- Each WWER-1000 basket contains up to 12 FA with maximum allowed residual heat **20 kW** and activity **2.41×10^{17} Bq**.
- The nuclear safety is ensured by the designed assembly pitch.
- The cooling system has to maintain the water temperature <**45°C**.
Dry Storage Facility (DSF) is designed for WWER-440 SNF built in 2011.

- Capacity of DSF – 78 containers.
- In January 2016 DSF has received its first 10 years license for operation. The transferring of the spent fuel WWER-440 from WSF has started.
- By the end of 2017 12 CONSTORs 440/84 loaded with SFA are stored in DSF.
- It is expected that by the end of 2025 all the WWER-440 FA will be stored in the DSF.
KNPP: Container for dry storage

- CONSTOR 440/84 - 84 fuel assemblies with maximum allowed residual heat 20.3 kW and activity $2.3 \times 10^{17}$ Bq.
- Maximum dose rate at the surface of the container is $P_{\gamma+n} \sim 40-200 \text{ \(\mu\text{Sv}/\text{h}\)}$ (middle of the upper lid). In the Terms of reference the maximum allowed value was $2000 \text{ \(\mu\text{Sv}/\text{h}\)}$.
- Maximum surface temperature is 90°C.
- Storage term – 50 years.
KNPP: Spent fuel generated by the end of 2017

Total: \( \sim 2174 \text{ tHM} \)

- WWER-440 Fuel assemblies
- WWER-1000 Fuel assemblies

Generated Spent Fuel (assemblies)

Generated Spent Fuel (tons HM)
KNPP: SNF stored onsite
by the end of 2017

- 720 WWER-440 fuel assemblies
- 1,856 WWER-1000 fuel assemblies
- 651 SNF stored onsite by the end of 2017
- 1,008 SNF stored onsite by the end of 2017

Total ~ 884 tHM

2,864 WWER-440 fuel assemblies
1,371 WWER-1000 fuel assemblies

Stored Spent Fuel

Number of Assemblies

- WWER-440
- WWER-1000

year

Tons Heavy Metal

year
KNPP: SNF Transport equipment - WSF

ТУК-6
for WWER-440 SNF

ТУК-13
For WWER-1000 SNF
During transportation a special convoy is arranged, including the vehicle with the container, firefighting machine, ambulance, radiation monitoring, security and police vehicles.
“Bulgaria does not have the capacity to implement a full nuclear fuel cycle. At present, Bulgaria has adopted an open nuclear fuel cycle policy. After irradiation of the fuel in the reactor cores, the spent fuel is sent for processing in Russia, with the subsequent return of high-level radioactive waste. In this regard, national practice in SNF management is linked to storing spent fuel at the Kozloduy NPP site in reactor pools and spent fuel wet storage facilities, with the subsequent disposal of SNF for further storage and processing.”

*Revised Strategy for SNF and RAW management up to 2030*
For SNF shipment along the Danube river a special dumb-barge is used with a capacity of 8 containers ТУК-6 or ТУК-13.

The barge is equipped with passive and powered cooling systems, 2 diesel generators, decontamination system, radiation monitoring system, container parameters control system and other relevant equipment.
KNPP: SF Shipment for Reprocessing

- 7296 WWER-440 fuel assemblies
- 959 WWER-1000 fuel assemblies

\[ \sim 1290 \text{ tHM} \]

1979 – 2017

\[ \sim 59\% \] of the SNF generated has been sent for technological storage and reprocessing in Russia
After the reprocessing of 927 tHM (the quantity of the nuclear material transported post 1989), Bulgaria will receive the respective quantity of vitrified HLW.
Kozloduy NPP SNF Management

Conclusions

- Storage option assures safely storing until spent fuel reprocessing or disposal. The presence of operating Wet and Dry Spent Fuel Storage Facilities, where the assemblies from both types of reactors are stored, provide safe effective and flexible management of Nuclear Fuel Cycle back-end.

- Reprocessing SNF provides long term strategic flexibility and confidence, preserves natural resources, reduces the volume of high-level waste to be disposed.
According to the Program for Spent Fuel Management ID ДОД.ЯГЦ.ПМ-283/06, the forecast for generating of SNF are based on the following milestones:

- Transition of Unit 5 to 104% power uprate transition of both units to use of advanced fuel.

- Currently only the Russian Federation offers temporary technological storage and following reprocessing service for fuel, manufactured in Russia.

- After 2020 there is possibility for nuclear fuel supply by alternative vendor also (diversifying the front end of NFC services).

There are 3 main options (scenarios) resulting from these.
Option 1: Operation of units 5 and 6 with fuel assemblies, supplied by TVEL JSC after 2020, including transport of SNF

After 2020 performing an annual transport for reprocessing of ~50 tHM (i.e. 5 transportations of SNF each with 96 assemblies within each 4 years) from WWER-1000, the SNF from WWER-1000 stored onsite before the end of 2017 and the Russian SNF which will be generated until the shutdown of the two units (2047 for unit 5 and 2051 for unit 6) could be transported for reprocessing until 2056.
Forecast for generation of SNF after 31.12.2017

Material Balance of SNF for Option 1

Operation of units 5 and 6 with fuel assemblies, supplied by TVEL JSC after 2020, including transport of SNF
Option 2: Operation of units 5 and 6 with fuel assemblies, supplied by TVEL JSC and/or alternative vendor after 2020 without transport of SNF

In case of building of DSF for WWER-1000 assemblies and its commissioning in 2030, the SNF stored onsite before the end of 2017 and the SNF that will be generated until the shutdown of the units could be transferred from the reactor pools and the WSF until 2054. Filling of 6 containers (114 assemblies) with SNF from WWER-1000 for dry storage and 10 containers (190 assemblies) per year after 2047, the transferring from WSF to DSF for WWER-1000 will finish approximately in 2058.
Forecast for generation of SNF after 31.12.2017

Material Balance of SNF for Option 2
Operation of units 5 and 6 with fuel assemblies, supplied by TVEL JSC and/or alternative vendor after 2020 without transport of SNF
Option 3: Operation of units 5 and 6 with fuel assemblies, supplied by TVEL JSC and/or alternative vendor after 2020 with transport of SNF:

In case of building of DSF for WWER-1000 SNF assemblies and its commissioning in 2030, as long as performing of transport of ~40 tHM (1 transportation of 96 Russian assemblies) SNF after 2020, the SNF stored onsite until the shutdown of the units could be transferred/transported from the reactor pools of units 5 and 6 and the WSF until 2056.
Forecast for generation of SNF after 31.12.2017

Material Balance of SNF for Option 3

Operation of units 5 and 6 with fuel assemblies, supplied by TVEL JSC and/or alternative vendor after 2020 with transport of SNF.

![Graph showing SNF generation over time with various data points and lines indicating different categories such as SNF assemblies, SNF in WWER-1000, SNF in WWER-440, and their respective filled capacities.](image-url)
Forecast for generation of SNF after 31.12.2017

SNF stored on the site of KNPP with and w/out transportation of WWER-1000 SNF assemblies for reprocessing after 2020

- SNF stored onsite with transportation IF units 5 and 6 are working with AO 'TVEL' fuel assemblies until 2047 and 2051 respectively
- SNF stored onsite with transportation of fuel assemblies by AO 'TVEL' and w/out transportation of the fuel assemblies by the alternative manufacturer
- SNF stored onsite w/out transportation of any fuel assemblies (resident and/or alternative)
**Forecast for generation of SNF after 31.12.2017**

**Back-up plan:** Currently, Terms of Reference have been developed for preparation of analysis for assessment of the possibility for using of the existing DSF – stage 1a for storage of WWER-1000 SNF and a team for preparation of tender documentation has been summoned. Stage 1a of the DSF was meant for storage of 32 CONSTOR 440/84 for WWER-440 SNF.

Because of the continuous transportation for technological storage and reprocessing of this type of fuel until 2017, this space remains free and it is logically reasonable the possibility to be considered for their usage in the means of storing of WWER-1000 SNF.

In case of obtaining of a permit or license for such storage of WWER-1000 SNF and depending on the type of the containers used, up to 608 assemblies could be stored, which will allow additionally up to 7 years of operation of the units 5 and 6 after reaching the maximum allowed capacity of WSF after 2030.
The development and support for the current system of staff training and retraining is a determining factor for the reliable and safe operation of nuclear power plants, including activities relating to the management of spent nuclear fuel and radioactive waste.

The training of specialists in the nuclear industry in universities and later further training directly at nuclear power plants is a major task for the nuclear energy sector.

Revised Strategy for SNF and RAW management up to 2030
Mechanisms for Knowledge Management

Human Resources

The system for preparing and qualifying staff in nuclear energy in Bulgaria takes a multilevel approach and includes:

1. Secondary vocational training
   - Marie Skłodowska Curie Secondary Vocational School for Nuclear Energy, Belene
   - Igor Kurchatov Secondary Vocational School for Nuclear Energy, Kozloduy

2. Higher education for obtaining the appropriate level of educational qualifications in natural and technical sciences and PhD
   - Sofia Technical University
   - Sofia University St. Kliment Ohridski

3. Initial and further specialist training
THANK YOU for your attention!