# WWER-1000 Nuclear Fuel Manufacturing Process at PJSC MSZ

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This report contains description of WWER-1000 fuel manufacturing process steps at PJSC MSZ and points out process key innovations implemented recently.

## 1. Nuclear Fuel Manufacture at PJSC MSZ

In general manufacturing steps of product delivered to NPPs is as follows: powder fabrication operations, pellet manufacture including pressing and sintering, zirconium cladding loading with pellets, fuel rod bundle formation and FA completion.

Further goes brief description of product manufacturing process steps and implemented innovations viewed in details.

## 2. Uranium Dioxide Powder Fabrication

**Receipt** Uranium hexafluoride is delivered in 1 $m^3$ transport containers in total up to 3 tons. Uranium dioxide powder is fabricated by $UF_6$ continuous pyrohydrolytic transformation in $UO_2$ powder.

**Evaporation** Container of $UF_6$ is placed in a special chamber and heated with heating elements. Temperature, $UF_6$ pressure, container mass and system leak tightness are checked during heating and evaporation. $UF_6$ evaporates and moves through the manifold to the reactor with fluidized bed formed by fed to reactor gas mixture (nitrogen, hydrogen, water vapor).

**Conversion** $UF_6$ is fed to reactor through nozzles. In addition overheated vapor is fed to reactor through outer ring nozzle. Exothermic reaction takes place between $UF_6$ and overheated water vapor and ends in generation of uranium oxides.

Due to low density uranium oxides powder is carried along by withdrawn gas flow and is separated by ceramic filters in reactor upper part. Uranium oxides are partly transformed in $UO_2$ powder in fluidized bed.

**Reduction and defluorination** Screws transport the powder from reactors to rotating tubular furnace, where it is treated by gas mixture (nitrogen, hydrogen, water vapor) at ~700°C. Then obtained uranium dioxide powder proceeds for sieving (for definite grain-size composition) and for separation of ferromagnetic inclusions from the basic material.

**Homogenization** Powder lot (up to 3 tons) is homogenized in planetary-screw mixer after all process steps termination. The goal is to obtain homogeneous physicochemical and isotope composition.

**Packing** Then the powder is loaded into transport containers, inspected by Central Plant Laboratory for compliance with design documents requirements and forwarded to pelletizing facility.

## 3. Fuel pellet manufacture

Obtained uranium dioxide powder proceeds to pellet manufacture.

Compact powder is pressed into pellets performing checks of compression pressure, random visual appearance, pellet density after pressing. Green pellets automatically by pneumatic device are softly loaded into boats for sintering.

Then pellets are sintered at 1750°C. At this step operator checks beam cycle and temperature at sintering zones. After sintering pellet random inspection for density and geometry parameters is performed.

Sintered pellets undergo grinding. Pellet geometry is finished at this step. Geometric parameter inspection is performed by LaserMike automatic equipment.

As far as pellets are ceramic product they have a tendency to chip formation during process steps and transportation. That’s why very strict requirements are applied to pellet visual inspection.

Pellet visual inspection is low-output as pellet inspection and rejection are preformed manually.

In 2014 Automated Pellet Inspection System was commissioned which helped to increase output at pellet inspection station significantly.

Implementation of equipment for pellet automated final inspection and pellet loading on trays in our manufacturing process allowed to avoid pellet damages in principle at significant manufacturing steps: starting from pellet grinding to their packing in transport containers and loading in fuel rods. Equipment output is up to 5 pellets per second.

This equipment is a system of interconnected modules-stations:

### 3.1. Station for Pellet Circumference Visual Inspection

Conveyor belt at constant speed transports a pellet column (up to 30 pellets) to the rollers where pellets are rotated. During pellet rotation two linear scanning cameras form pellet circumference image. Program software performs pellet sorting based on set pellet visual standards requirements.

Checked pellet column is fed to sorting station consisting of conveyor belt (for gap forming between pellets) and pneumatic blow-off. Industrial computer gives rejected pellet code to equipment control unit. Control unit processes codes of pellets passing along the optical couple and commands to blow off the rejected pellet to rejection box.

### 3.2. Station for Pellet End Faces Visual Inspection

Pellets that passed circumference inspection undergo end face inspection one by one. Pellets move on belt conveyor and in its upper point break optical detector signal. Then on detector command optical system switches on to inspect pellet first end face. Computer processes inspection result and accepts or rejects the pellet. In case of rejection equipment blows off the rejected pellet. The second end face inspection is performed in a similar way.

### 3.3. Station for Final Visual Inspection

Random sampling scope (500 pellets) is stacked automatically on QC visual inspection tray. Based on QC inspection results pellet lot final acceptance is performed.

### 3.4. Station for Pellet Loading on Trays

Empty container is weighed before packing. Then on control unit command empty tray is placed by pneumatic device on conveyor belt for loading.

Pellets are on conveyor belt of pellet column formation equipment. This equipment forms pellet columns of rated length and stacks them on trays until tray is filled. On control unit signal a tray packed with pellets by mechanical device is moved to a stack of packed trays. When trays are packed with pellets and stacks of trays are complete they are loaded in a transport container. Container is packed and weighed.

## 4. Fuel Rod Manufacture

WWER-1000 fuel rods manufacture is performed at automated lines.

New line for VVER-type fuel rod manufacture was commissioned in 2009 instead of those with ended life-time. All the equipment is developed and installed by PJSC MSZ Engineering Center specialists. The newly developed line includes tray loading technology and cladding bar code marking by laser. In 2012 new manufacturing process for fuel rods and FAs was developed and two manufacturing lines (fuel rod and FA) were combined.

Since 2011 UGd fuel rod manufacture is performed in newly organized area. UGd fuel rod manufacturing area was distant before. To locate all types of fuel manufacture in one building UGd FR (fuel rod) manufacturing area was moved and reequipped.

In the result WWER-1000-type fuel is manufactured now from pellet to FA in one building. It saves transport costs, reduces repacking operations and other steps.

FR manufacturing procedure is the following:

FR manufacturing steps

1. Components acceptance (cladding and components documents checks, cladding surface visual inspection, checks of cladding straightness and length, cladding blow off)
2. Cladding and bottom end plug butt resistant welding
3. Fuel column loading, fuel column mass check, compression spring insertion, plenum volume length check, check of compression spring correct position, dedusting. For FR manufacture pellet loading from trays is used. It minimizes pellet damages during transportation steps and loading.
4. FR vacuuming and preliminary filling with pressurized helium
5. Cladding and top end plug butt resistant welding (pressurization)

FR inspection steps

1. FR length check – 100%
2. Checks of helium pressure in the cladding

– 100% non-destructive – inductive-convectional method

3. Leak test – 100% – vacuum chamber mass spectrometric. Welds surface temperature shall be at least 160°C (for Temelin NPP), for other FRs – room temperature.
4. Checks of weld seam continuity – 100% ultra sonic inspection + samples metallographic inspection – accepting and releasing (in the beginning and end of welding shifts)
5. Checks for compression spring presence – continuous – eddy-current method
6. Fuel column checks for gaps – continuous – gamma-absorptive method
7. Checks of U-235 content in uranium – continuous auto-emissive
8. Checks of FR surface for contamination – one certificate per shift at contamination check station
9. Leak test and visual inspection – continuous, visual using special tools (gages, snaps) and universal measuring tools
10. Checks of UGd fuel rods for pellets with other $Gd_2O_3$ contents - continuous – eddy-current

Use of state-of-the-art FR manufacturing and inspection technologies at automated lines with high-quality equipment allows to fabricate high-quality product with ≈ 0.1% rejects.

## 5. Working Assembly (WA) and Fuel Assembly (FA) Manufacture

Further on fuel rods proceed to FA manufacture.

In 2012 in building 274 improved area for WWER-1000 FA manufacture was developed. FA manufacturing area is continuation of FR manufacturing line. After line relocating FA manufacturing process was not changed except for the means of FR passing for bundle forming and lacquering.

One of the key tasks of new manufacturing area development was its consistency to FR manufacturing line. New devices were applied. So for FA manufacturing area and automated line interaction interim frame was performed. Interim frame consists of 6 cells (only one fuel rod design for each cell). In compliance with the specified program fuel rods complete are loaded in interim frame: not more than 312 fuel rods. Interim frame with fuel rods is moved to unloading station. Its fuel rods are equal to one FA bundle. According to the fixed plan of fuel rod assembling into bundle automated interim frame FR unloading sequence is performed.

Before combined manufacturing area development fuel rods were composed into lots and packed in container at FR manufacturing area. Then they were transferred to assembling area and were repacked in interim container. Operator sorted out fuel rods in special sequence in interim container cells manually. To pack fuel rods paper and cardboard were used. Containers were inspected and maintained periodically. Fuel rod automated moving from manufacturing line to FA assembling area reduced significantly expenses due to logistics optimization and resources saving and increased output.

Unloaded fuel rods from interim frame proceed to lacquering station. At the equipment used before fuel rods were dipped (hanging vertically) into tank with lacquer and then dried.

Equipment of the new manufacturing area allows to lacquer fuel rods and dry them in horizontal position on their pass. This technology doesn't break fuel rod sequence for further use. Lacquered fuel rods are placed in the storage near assembling area. Before fuel rods proceed to automated bundle forming station their codes are read and related to FA defined cell.

Bundle skeleton is placed at the assembly bench and skeleton is loaded with fuel rods.

Further operations are as follows:

- lacquer washing off and drying in retorts;
- tail piece is welded to fuel rod bundle;
- top nozzle assembling;
- geometry checks and visual inspection;
- packing in transport container and transferring to finished product storage.