DESIGN AND FABRICATION OF NUCLEAR FUEL FOR WWER AND RBMK REACTORS

Workshop on “Modelling and Quality Control for Advanced and Innovative Fuel Technologies”

14-25 November 2005

The Abdu Salam International Centre for Theoretical Physics, Trieste, Italy

Presented by V. Onufriev - consultant

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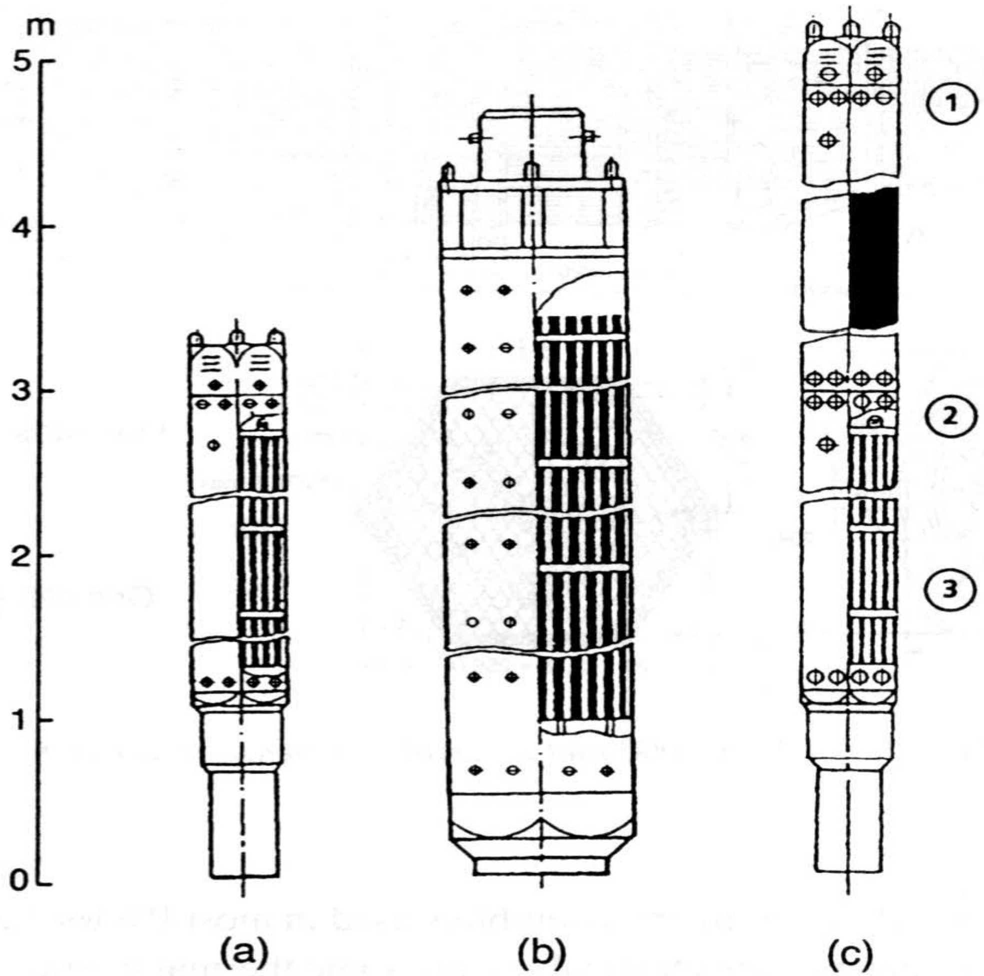


FIG. 1. (a) WWER-440 operating FA; (b) WWER-1000 FA; (c) WWER-440 control rod: (1) bar to drive, (2) absorber part, (3) fuel part.

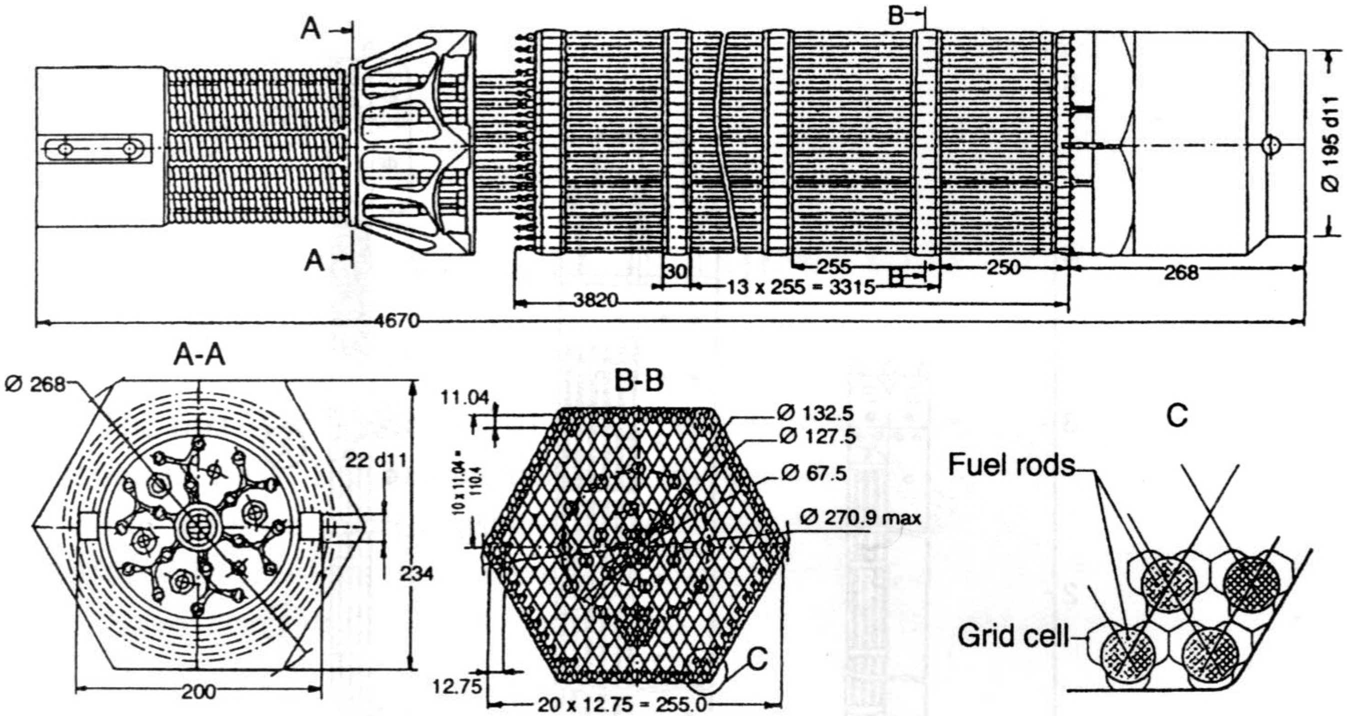
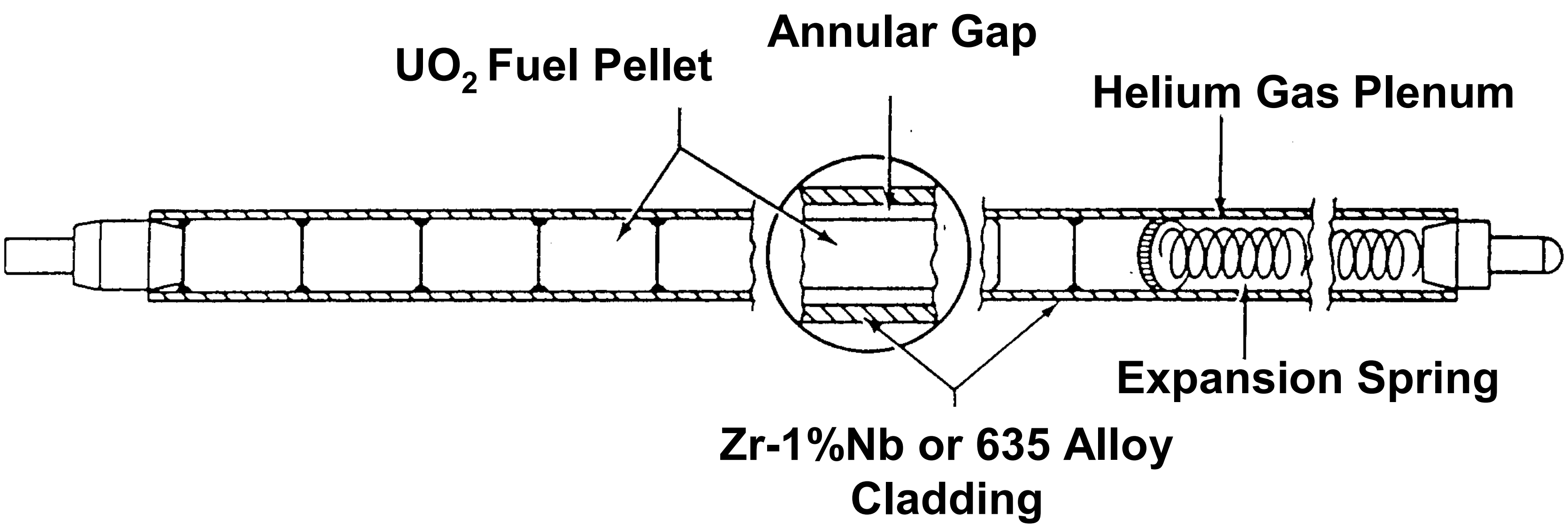


FIG. 2. WWER-1000 fuel assembly. Dimensions are in mm.

Principal Design of a LWR Fuel Element



Basic design parameters of WWER fuel (NEI, Sept. 2003)

VVER design data

	Mashinostroitelny zavod				Westinghouse	
	VVER 440 Serial	VVER 440 Serial U-Gd Fuel	VVER 440 Advanced CFA[2]	VVER 1000A	440	Vvantage 6 1000
Assembly geometry	Hex	Hex	Hex	Hex	Hex	Hex
No of rods per assembly	127	127	127	331	127	
– Fuelled	126	126	126	312	126	312
– Unfuelled	1	1	1	19	1	0
Overall assembly length (mm)	3217	3217	3200	4570	3188	4583
Overall assembly width (mm)	145	145	144	234.5	144	235
Rod length (mm)	2536/2546[1]	2536/2546[1]	2536	3837	2520	3889
Rod outside diameter (mm)	9.1	9.1	9.1	9.1	8.90	9.14
Pellet length (mm)	9-11	9-11	9-11	9-11	9.15	9.40
Pellet outside diameter (mm)	7.57	7.57	7.57	7.57	7.63	7.84
Pellet density (g/cm^3 or TD)	10.4-10.7	10.4-10.7	10.4-10.7	10.4-10.7		95%
Average linear fuel rating (kW/m)	12.96	12.96	12.96	16.7	15	
Peak linear fuel rating (kW/m)	32.5	32.5	32.5	44.8	35	
Maximum fuel temperature (°C)	1500	1500	1500	1667	-	
Clad material	Zr1%Nb	Zr1%Nb	Zr1%Nb	see note[3]	Zr4	Zy4
Clad thickness (mm)	0.63	0.63	0.63	0.63	0.55	0.57
Average clad temperature (°C)	–	–	–	–	–	–
Maximum clad temperature (°C)	350	350	350	–	360	–
Grid material	Zr1%Nb	Zr1%Nb	Zr1%Nb	Zr1%Nb	Zr4	Zy4
Average discharge burnup (MWd/kgU)	42	-	-	55	>40	
Maximum assembly burnup (MWd/kgU)	>50	53	50	60		>50

VVER 440 Serial and VVER 440 Serial U-Gd Fuel are removable for inspection purposes, whereas VVER 440 Advanced CFA is not.
[1]Fuel assembly design with removable fuel rods. [2]Control fuel assembly (contains six Hf slices). [3]Zr1%Nb, Zr1%Nb1.3%Sn0.3%Fe.
Hex=Hexagonal.

Basic WWER fuel design data (from "Design and performance of WWER Fuel", IAEA TRS 379, 1996)

TABLE IV. FUEL ELEMENT DESIGN PARAMETERS

Parameter	WWER-440	WWER-1000
Assembly length (m)	3.22	4.655
Number of fuel rods in assembly	126	312
Length of fuel rods (m)	2.55	3.84
Length of fuel stack (m)	2.42	3.53
Fuel cladding outside diameter (mm)	9.1	9.1
Fuel cladding inside diameter (mm)	7.72	7.72
Fuel cladding wall thickness (mm)	0.65	0.65
UO_2 pellet outside diameter (mm)	7.57	7.57
UO_2 pellet inside diameter (mm)	1.4–1.6	2.2–2.4
UO_2–cladding radial gap (mm)	0.075–0.13	0.075–0.13
UO_2 pellet shape	plain cylinder	chamfered
UO_2 pellet length (mm)	9–12	9–12
UO_2 pellet density (g/cm^3)	10.4–10.8	10.4–10.8[a]
UO_2 pellet grain size (mm)	10–15 μm	10–25 μm
UO_2 pellet densification, diametral (%)	0.4 max	0.4 max
Helium filling pressure (MPa)	0.5–0.6	2–2.5
Gas plenum volume (cm^3)	4	11.4
Total rod internal free volume (cm^3)	8.3	32
Fuel rod pitch (triangular) (mm)	12.2	12.75
Number of spacer grids	11	15
Fuel assembly width (mm)	144.2	234
Weight of uranium/rod (kg)	0.95	1.46
Weight of uranium/assembly (kg)	119.7	430

[a] 10.4–10.7 g/cm^3 since January 1995.

Basic design features of WWER reactor/fuel

Reactor Type: LW cooled, water moderated, FAs – hexagonal shape

Fuel Reload Type: During refuelling outages

Fuel: UO_2 or $(U+Gd)O_2$ enriched to:

- WWER-440 - 3.8% (4-5 years) or 4.2% for the 2nd generation (5 years); Gd rods have lower enrichment level
- WWER-1000 – 3.8-4.3% (4 years) and 4.9% for perspective 5 years residence time; about Gd rods-see slide Number 56
- Fuel pellets – with central hole, trend for hole diameter decrease

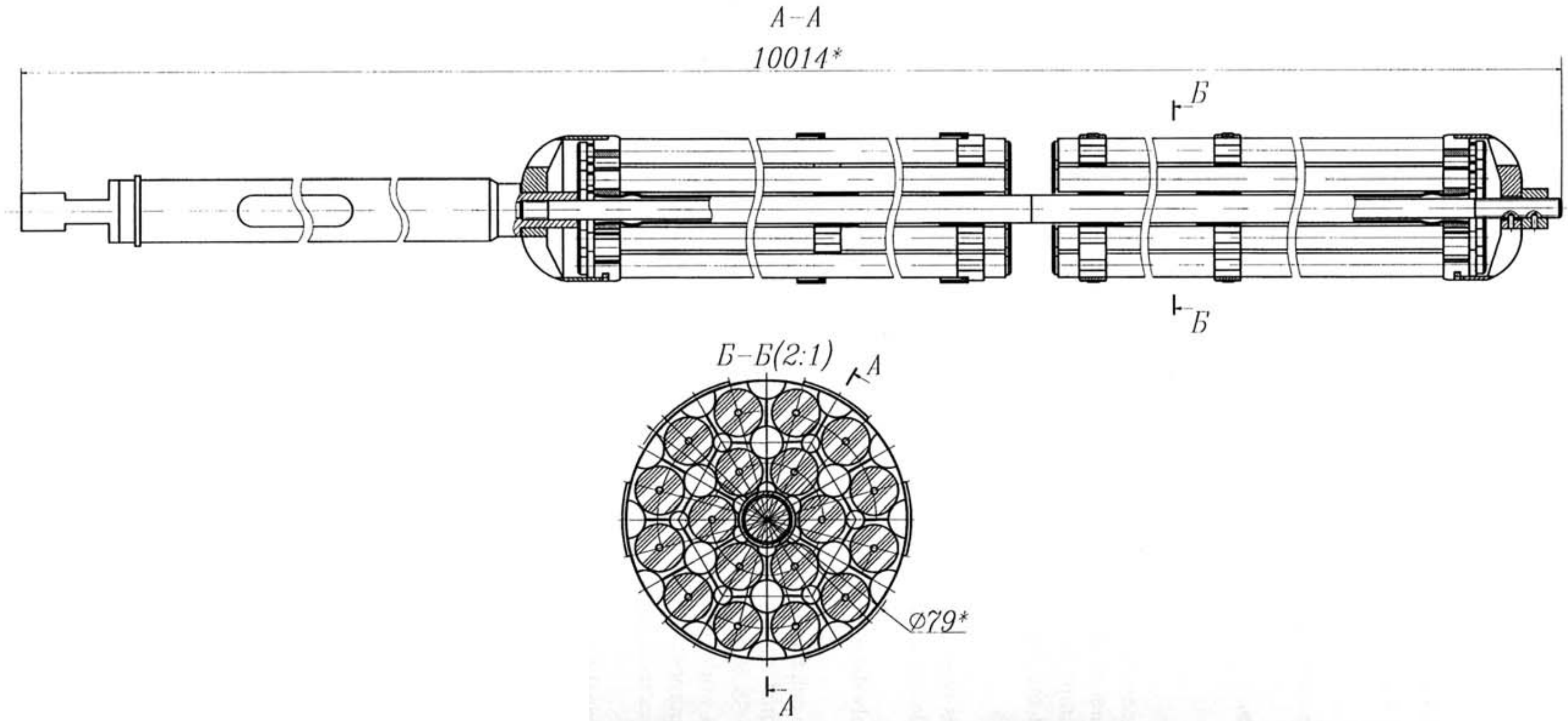
Tendency: Increase of enrichment, burnup, duration of the single fuel cycle and total residence time; decrease of FA consumption

Coolant Condition: Non-boiling, 12.5 (440) and 16.0 MPa (WWER-1000)

Clad Operational Mode: Free Standing, ~0.5 (~2.0) MPa He inner pressure for WWER-440(1000)

Tendency: Change for E635 alloy as cladding and SG material

RBMK-1000 Fuel Assembly Design



Basic design parameters of RBMK fuel (NEI, Sept. 2003)

RBMK design data

	Mashinostroitelny zavod			
	RBMK-1000		RBMK-1500	
	UO_2+Er (2.6% U^{235})	UO_2+Er (2.8% U^{235})	UO_2+Er (2.4% U^{235})	UO_2+Er (2.6% U^{235})
Assembly geometry	Circular array	Circular array	Circular array	Circular array
No of rods per assembly	37	37	37	37
– Fuelled	36	36	36	36
– Unfuelled	1	1	1	1
Overall assembly length (mm)	10014	10014	10014	10014
Overall assembly width (mm)	79	79	79	79
Rod length (mm)	3640	3640	3640	3640
Rod outside diameter (mm)	13.63	13.63	13.63	13.63
Pellet length (mm)	12-15	12-15	12-15	12-15
Pellet outside diameter (mm)	11.48	11.48	11.48	11.48
Pellet density (g/cm^3 or TD)	10.4-10.7	10.4-10.7	10.4-10.7	10.4-10.7
Average linear fuel rating (kW/m)	15.3	15.3	20.5	20.5
Peak linear fuel rating (kW/m)	35.0	35.0	42.5	42.5
Clad material	Zr1%Nb	Zr1%Nb	Zr1%Nb	Zr1%Nb
Clad thickness (mm)	0.86	0.86	0.86	0.86
Maximum clad temperature (°C)	350	350	350	350
Grid material	Zr1%Nb	Zr1%Nb	Stainless steel	Stainless steel
Average discharge burnup (MWd/kgU)	25.8	30	20.5	26
Maximum assembly burnup (MWd/kgU)	29.6	34.5	23.5	30

Basic design features of RBMK reactor/fuel

Reactor Type: LW cooled, graphite moderated, FAs in vertical pressure tubes
Fuel Reload Type: On-power

Fuel: (U+0.5% Er)O_2 enriched to 2.6%
Burnup, MWd/kg U: 27
FA consumption per year: 311
Tendency: Increase of Er content, enrichment and burnup, decrease of FA consumption

Coolant Condition: Boiling, up to 20% steam at outlet, 7 MPa, presence of free oxygen, possibility of nodular/crevice corrosion
Clad Operational Mode: Free Standing, 0.5 MPa He inner pressure
Tendency: Change for E635 alloy as cladding and SG material

Pressure Tube Material: E125 Alloy (Zr-2.5%Nb) in annealed condition

Separation Technologies in the World

Gaseous diffusion SSF=1.0043	USEC (USA) CNNC (China)	Eurodif (France)
Gas centrifuge SSF=1.25	**Rosatom (Russia)** JNFL (Japan) Kahuta (Pakistan)	Urenco (D, NL, UK) INB (Brazil) CNNC (China)

Under implementation:

Gas centrifuges of the 7th generation — Urenco, **Rosatom**, JNFL, USEC, COGEMA

Under research with insignificant financing:

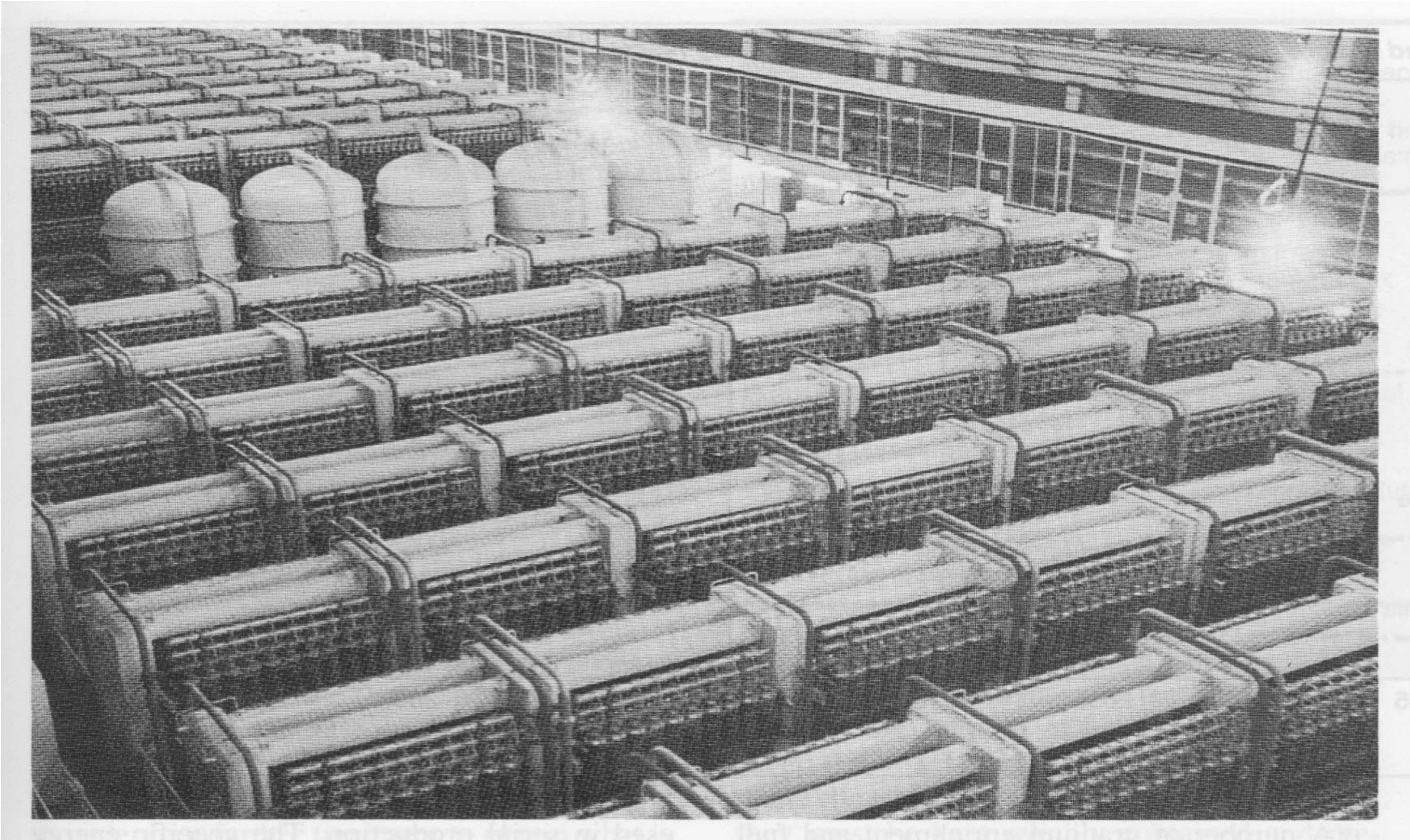
Atomic vapor laser isotope separation SSF=2	USEC / LLL - “SILEX” CEA - “SILVA” Laser-J	(USA) (France) (Japan)
Molecular laser isotope separation	SSL - “SILEX”	(Australia)

Type and capacity of operational enrichment plants worldwide (IAEA NFCIS data, status as of Dec. 2003)

Facility Name	Country	Type	Capacity, MTSWU
Paducah/USEC	USA	D	11300
Eurodif	France	D	10800
Ekaterinburg/Rosatom	**Russia**	**C**	**7000**
Siberian Chemical Combine/Rosatom	**Russia**	**C**	**4000**
Urenco Capenhurst	UK	C	2300
Urenco Nederland	Netherlands	C	2200
Urenco Deutschland	Germany	C	1800
JNFL Rokkasho	Japan	C	1050
Angarsk/Rosatom	**Russia**	**C**	**1000**
Krasnoyarsk/Rosatom	**Russia**	**C**	**1000**
Lanzhou 1	China	D	900
Shaanxi	China	C	200
Kahuta	Pakistan	C	5
(INB Resende)	Brazil	C	Start

C-Centrifuge; D-Diffusion

Enrichment services in Russia - Rosatom operates 4 plants with 13000 MTSWU/a capacity, see below photo of centrifuges in a shop of Krasnoyarsk



JSC TVEL is a manufacturer and supplier of Russian nuclear fuel – (1)

Development, manufacture, licensing and supply of WWER and RBMK fuels to Russian and foreign customers are done by the Joint Stock Company TVEL (JSC TVEL). JSC TVEL brings together enterprises, engaged in all areas of the nuclear fuel cycle and structurally operates as a Corporation. TVEL Corporation is an industrial commercial entity comprising JSC TVEL being the main company and its subsidiaries and affiliates. Apart of the above-mentioned services, TVEL Corporation provides scientific monitoring of fuel operation, including warranty on operation of reactor cores at NPPs.

JSC TVEL is a manufacturer and supplier of Russian nuclear fuel – (2)

Also, TVEL Corporation manufactures and supplies fuel for fast reactors, PWRs, research reactors, nuclear powered ships and submarines. In 2004, Corporation TVEL supplied fuel to about 80 power reactors worldwide in 13 countries accounting for 17% of world total. In 2004 fuel was supplied for initial cores of new WWER-1000 reactors including Kalinin Unit 3 (Russia), Tianwan Unit 1 (China), Khmelnitski Unit 2 and Rovno Unit 4 (Ukraine). In co-operation with FRAMATOME ANP, Corporation TVEL manufactures and supplies PWR fuel for power reactors to Netherlands, Switzerland and Sweden.

FUEL FABRICATION IN THE WORLD-MERGING FUEL VENDORS

- 4 biggest fuel vendors for LWR in the world:
- BNFL-Westinghouse-ABB plus EFG (W-Atom) in April 2000,
- Framatome-Siemens (Framatome-ANP) in July 2000,
- GE-Hitachi-Toshiba in 2000,
- JSC TVEL in 1996 (present share=17%)
- Plus several national LWR fuel fabricators with smaller capacities (Brazil, China, India, Japan, Korea)

TVEL Corporation enterprises (nuclear fuel component)

- **JSC Mashinostroitelny zavod (Electrostal, Moscow region) - powder, pellets, rods, FAs for WWERs, RBMKs, BN, submarines**

- **JSC Novosibirsk Chemical Concentrates Plant (Novosibirsk) – powder, pellets, rods, FAs for WWERs, RRs**

- **JSC Chepetsk Mechanical Plant (Glazov, Udmurt Republic) – Zr alloy components**

JSC Ulba Metallurgical Plant (Ust-Kamenogorsk, Kazakhstan)

– TVEL Corporation partner, also through JSC JV UKR TVS (Russia+Ukraine+Kazakhstan)

– Ulba plant produces powder and pellets for Novosibirsk plant and RBMK repU pellets for Electrostal plant

– Main areas of JSC JV UKR TVS activity: improvement and development of nuclear fuel production in Ukraine, Russia and Kazakhstan, creation and development of new industrial and technological ties between the enterprises of Ukraine, Russia and Kazakhstan; provision of Ukrainian NPPs with nuclear fuel.

QA/QC and Quality Management Systems certification

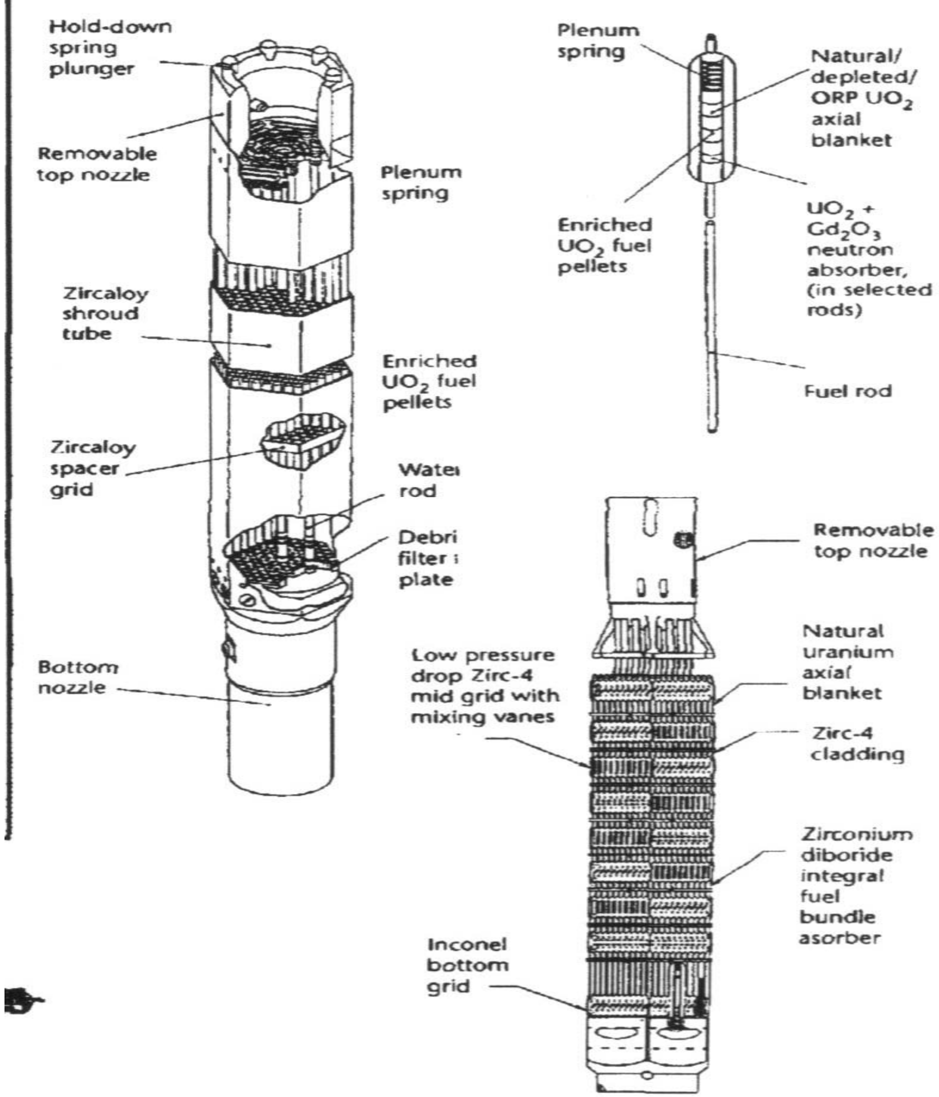
- TVEL Corporation obtained certificate of Quality Management System compliance with ISO 9001 (version 2001) after auditing by TUV (Germany) in December 2004
- Electrostal, Novosibirsk and Glazov plants passed through the same procedure in 2003-04 and received certificate of Quality Management System compliance with ISO 9001 (version 2000) and Ecology Management certificate ISO 14001
- QA/QC Systems of Electrostal, Novosibirsk and Glazov plants were audited and certified by TUV (Germany) as complying to the ISO 9001 (versions 1997 and 2000)

Alternative WWER Fuel Suppliers

- **WWER-440 fuel alternative supplier is BNFL of BNFL-W-ABB Group. Fuel was/is supplied as partial reload batch fuel to Paks and Loviisa NPPs.**
- **W of BNFL-W-ABB Group supplies WWER-1000 fuel to Temelin NPP, Czech Republic. Corporation TVEL is an alternative supplier in this case.**
- **W of BNFL-W-ABB Group delivered in the 2nd quarter 2005 six WWER-1000 FAs to the South-Ukranian NPP, Unit 3 as a trial. If it is OK, 42 more FAs will be delivered in 2006-07.**

Westinghouse

Typical VVER-1000 fuel assembly (UO_2 fuel)



Major Stages in WWER/RBMK Fuel Fabrication)

- **Conversion of UF_6 gas into UO_2 powder (Dry-gas flame or Wet-ADU route)**
- **The uranyl-nitrate fusion cake from RT-1 plant serves as raw material for fabrication of the RepU fuel pellets for RBMKs and test FAs for WWERs (ADU process)**
- **Pellet fabrication (powder preparation, pressing, sintering, grinding, drying, inspection**
- **Rod assembling ← components (claddings, plugs, springs,..)**
- **FA assembling ← components (rods, CRs, SGs, top and bottom nozzles, guide tubes, filters,..)**

Uranium Oxide Fuel Manufacture

Convert UF_6 to UO_2

Dry Route-Principal chemical reactions

$$UF_6 + 2\ H_2O \rightarrow UO_2F_2 + 4\ HF \text{ (Hydrolysis)}$$

$$UO_2F_2 + H2 \rightarrow UO_2 + 2HF \text{ (Reduction)}$$

Total Reaction:

$$UF_6 + 2\ H_2O + H_2 \rightarrow UO_2 + 6\ HF$$

Conversion of UF_6 to UO_2

Wet Routes

Ammonium Diuranate (ADU)

UF_6 Vapour
Steam (200°C)
UO_2F_2 plus HF
Add, Stir Ammonia, Dilute Nitric Acid (60°C)
ADU Precipitate
Filter/Wash (Ammonia)/Dry
UO_3
Reduce by adding H_2 (820°C)
UO_2

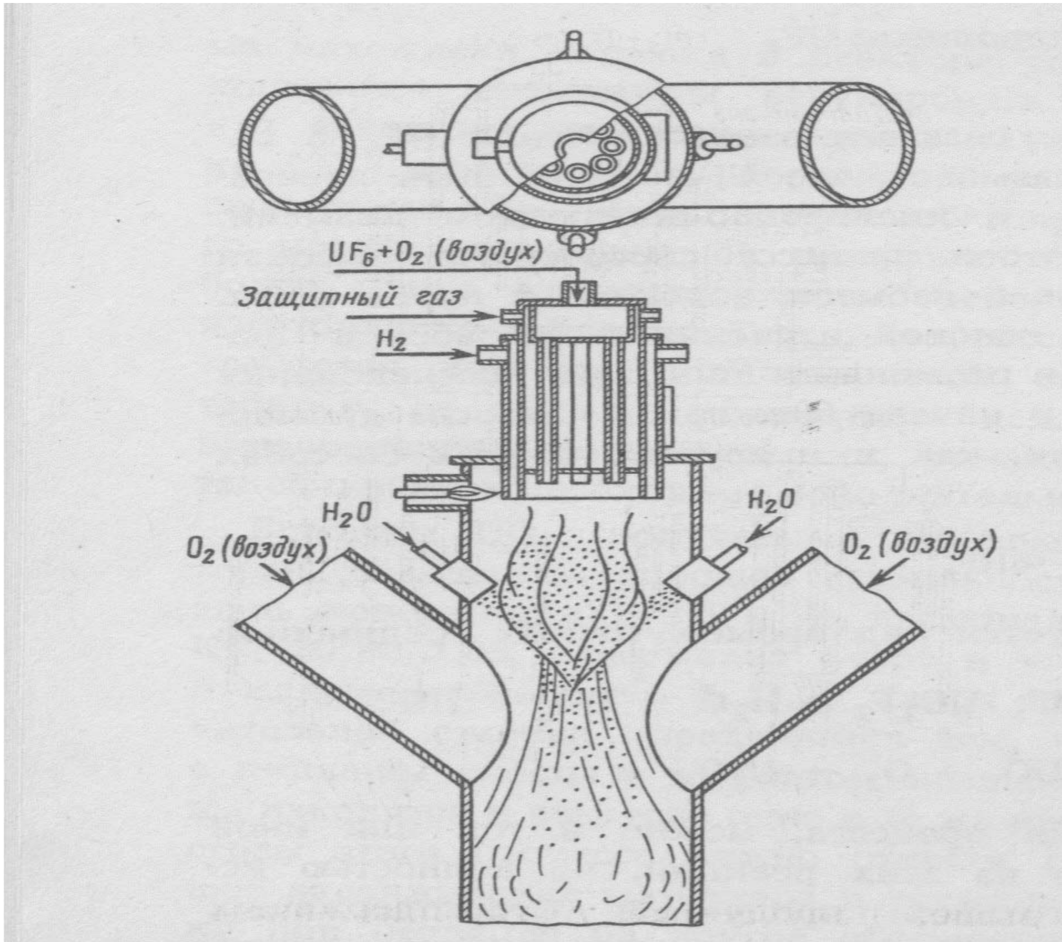
Ammonium Uranyl Carbonate (AUC)

UF_6 Vapour
Add Water, Ammonia, CO_2 (50°C)
AUC Precipitate slurry
Filter/Wash/Dry
AUC cake
Fluid Bed Reaction Chamber
Steam, H_2, N_2 (500°C)
UO_2

Uranium Oxide Fuel Manufacture

Convert UF_6 to UO_2

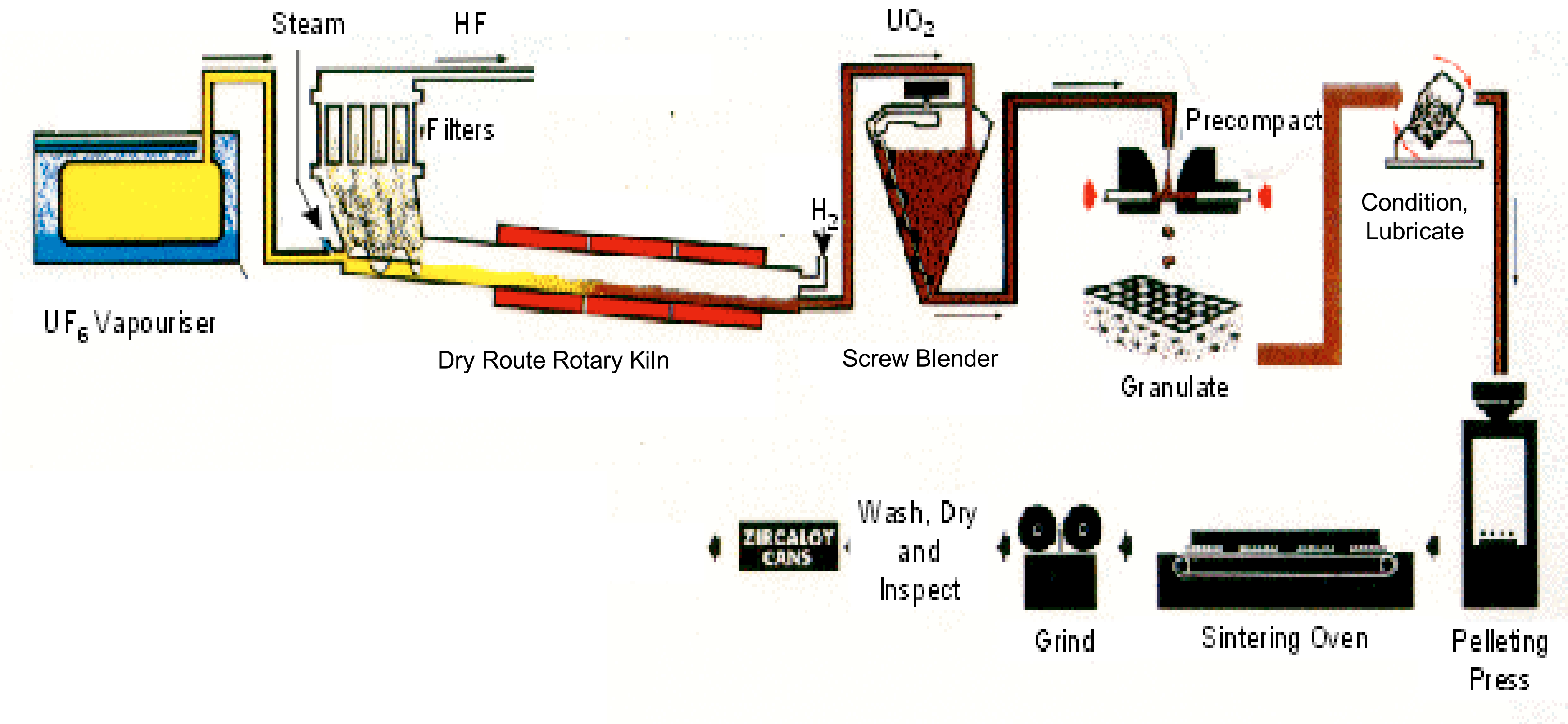
Flame Reactor-Principal scheme, not specific to Electrostal plant,



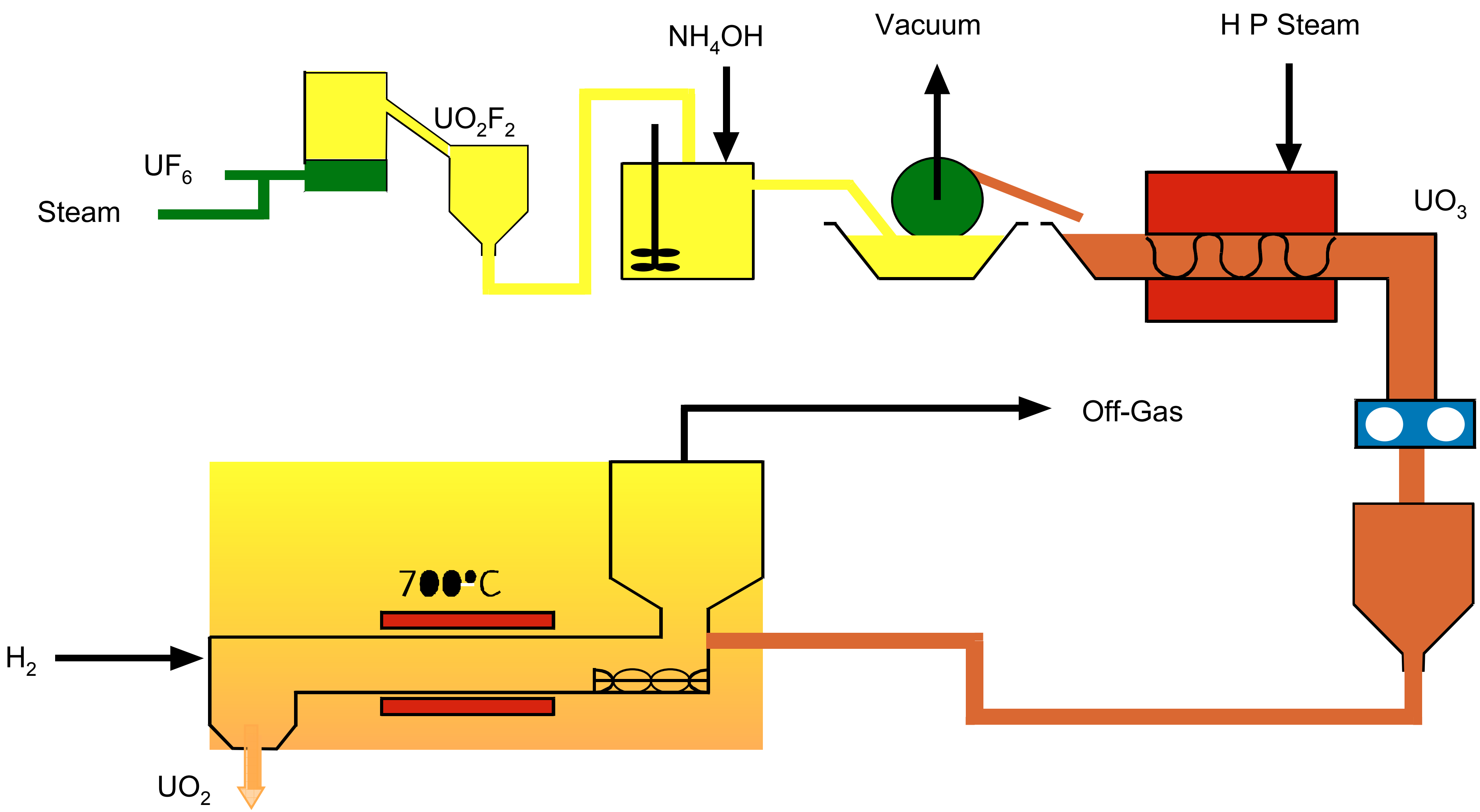
Uranium Oxide Fuel Manufacture

Convert UF_6 to UO_2

Dry Route-Principal scheme, not specific to Electrostal plant



ADU Process



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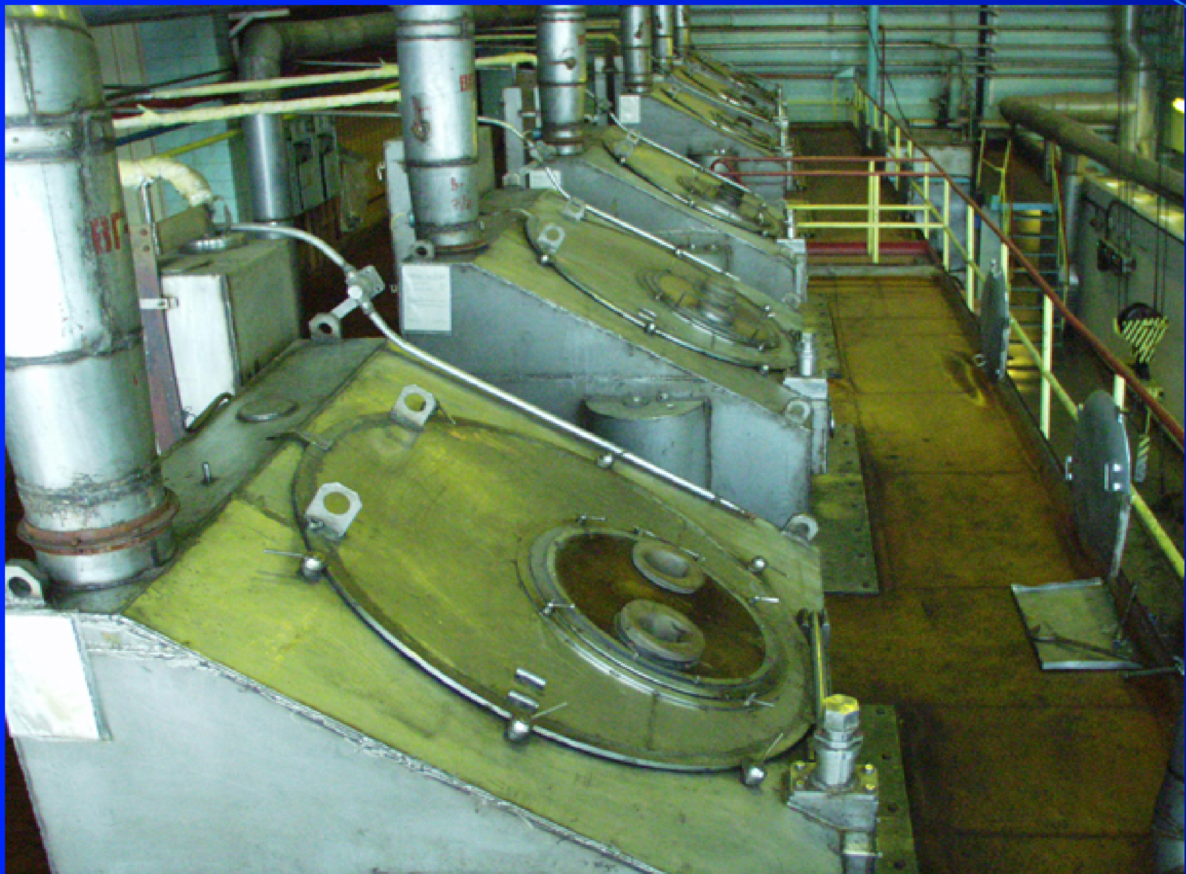
PROCESS OF UO_2 POWDERS PRODUCTION-

Yashin, S.A., et al, IAEA TECDOC-1416, p.55



UF_6
$^{235}U \leq 5.0\%$

$Al(NO_3)_3$

hydrolysis

Extraction –
Re-extraction

TBP

Ammonium poliuranate
precitation

NH_4OH

Filtration

Drying,
Thermal decomposition

Reduction

H_2

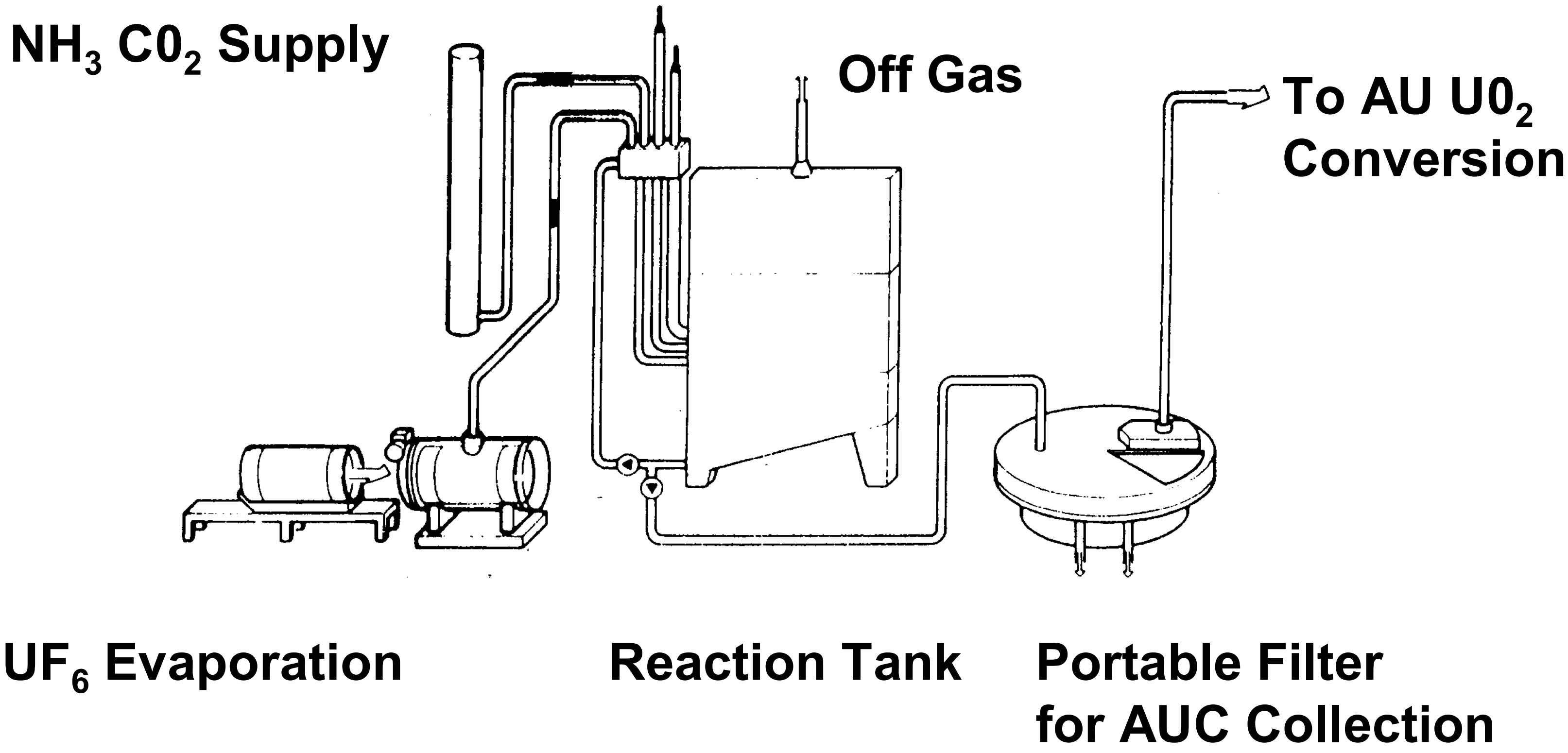
Homogenization

UO_2


1272



Conversion of UF_6 to AUC



Conversion of AUC to UO_2 Powder

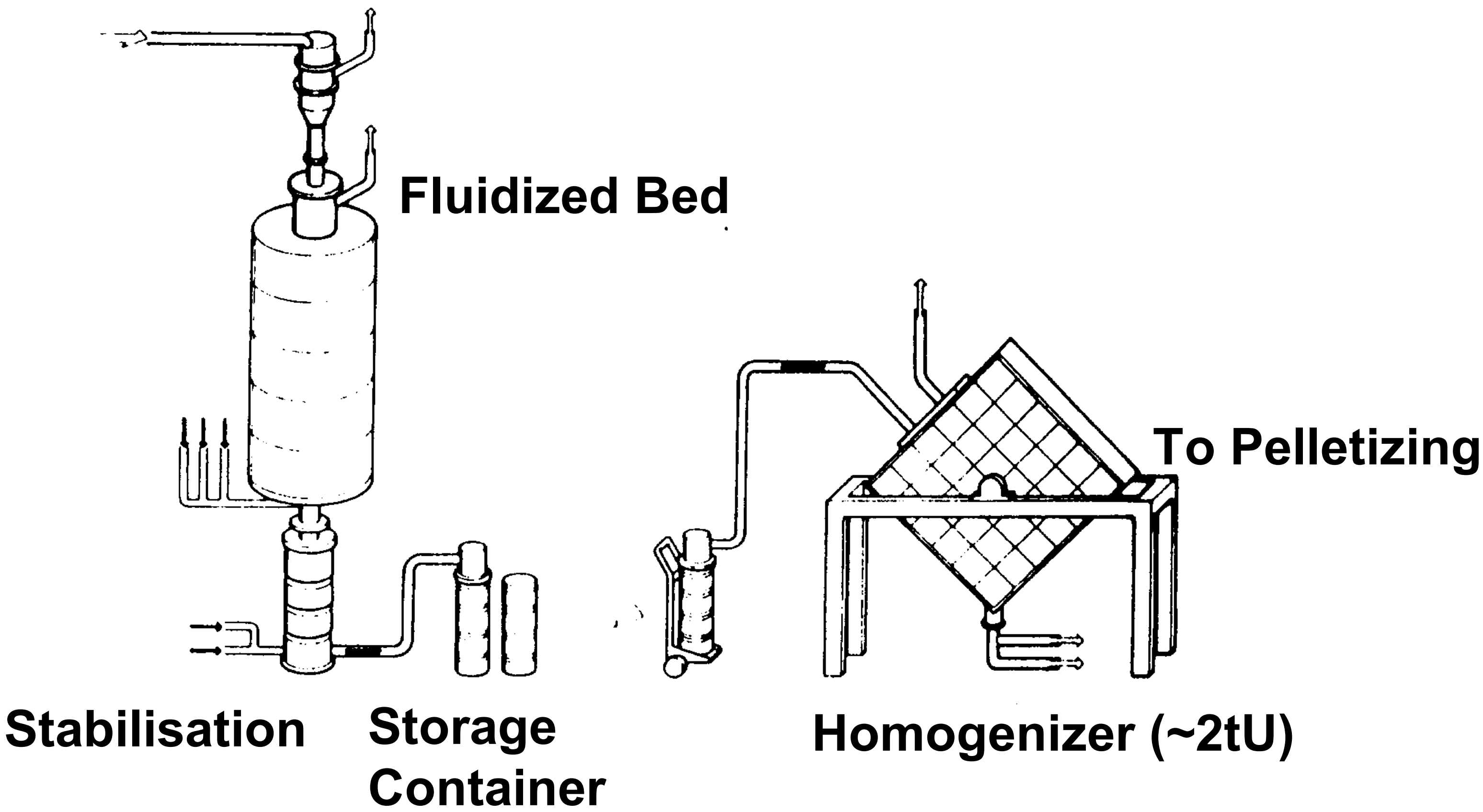
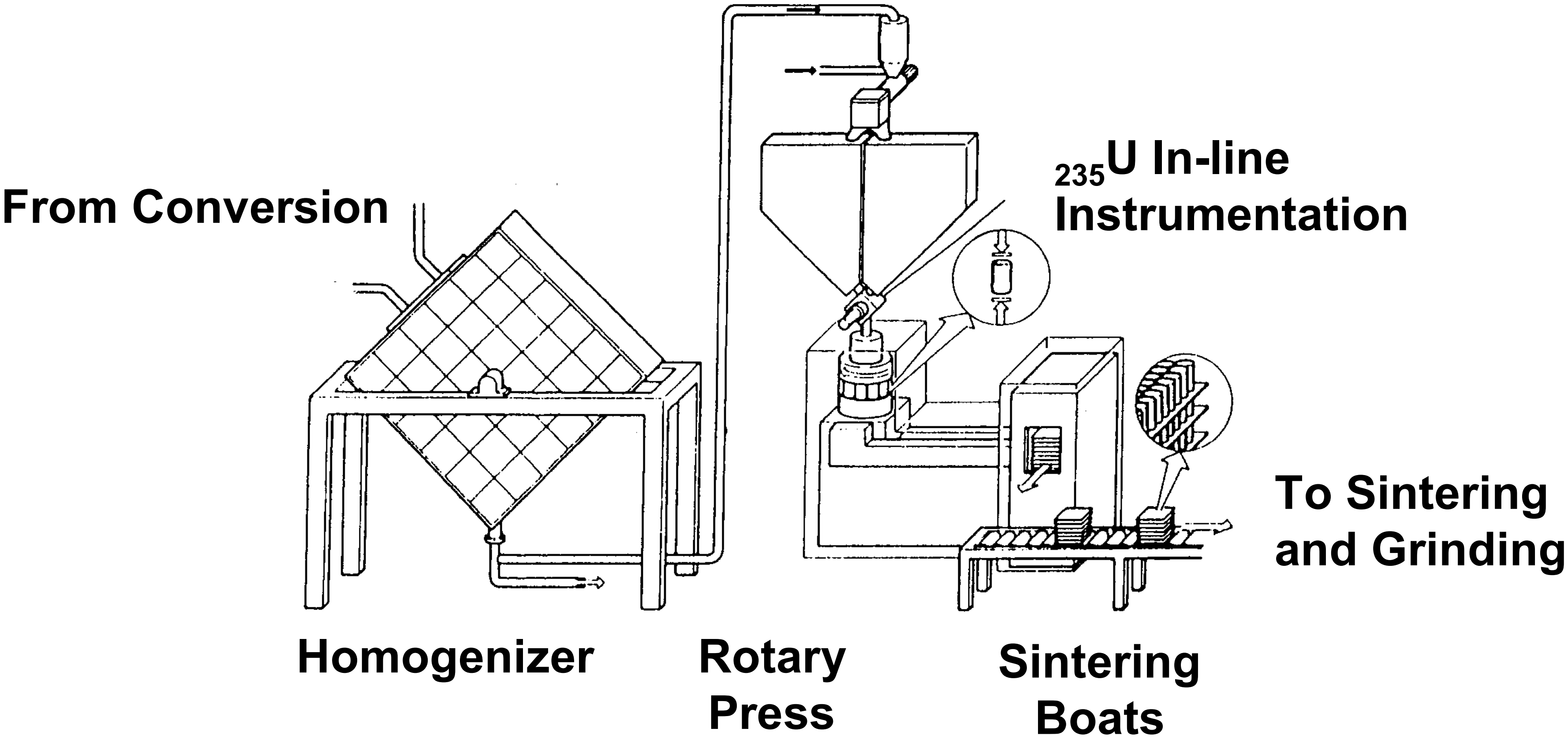


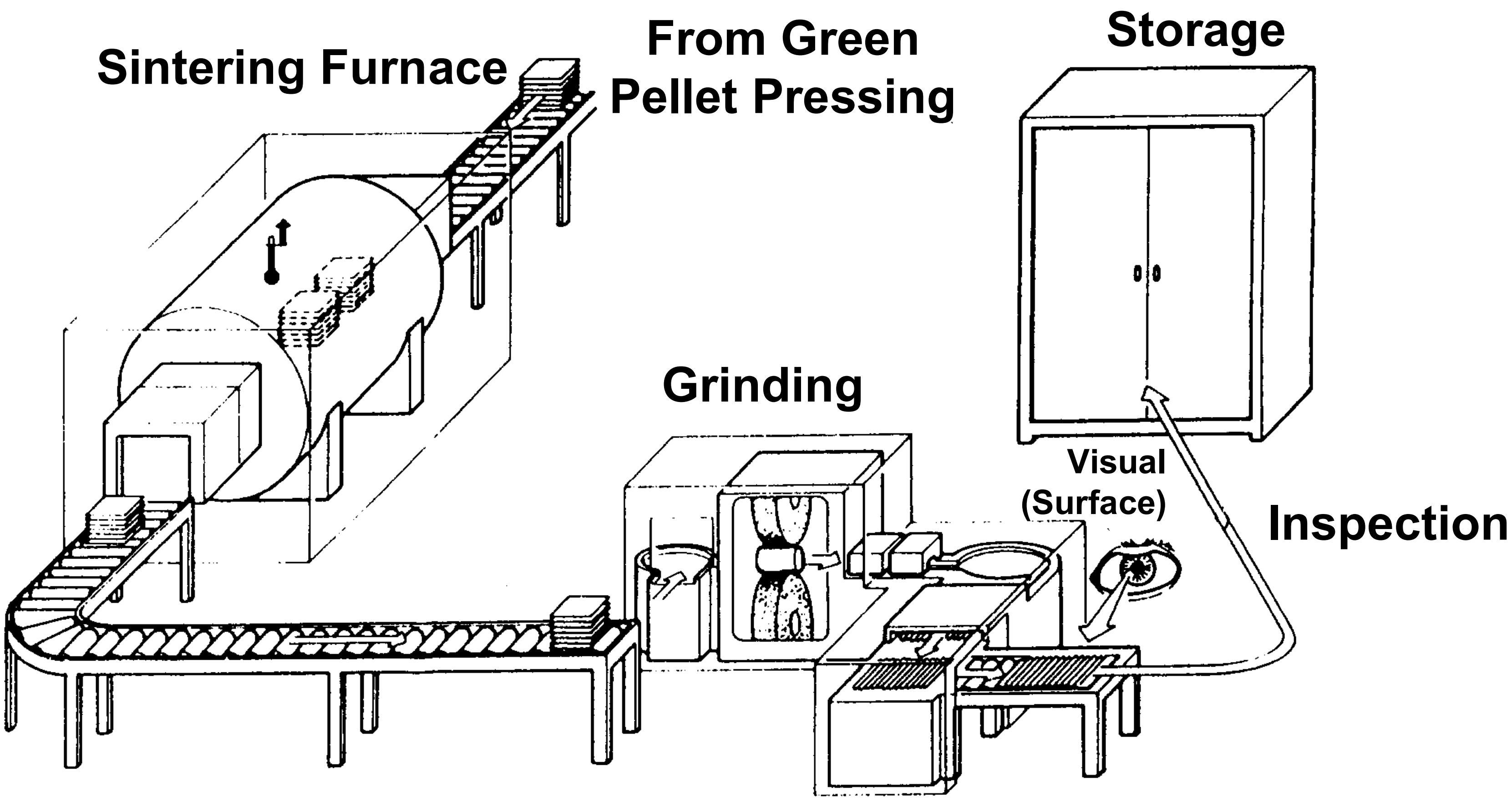
Table 1. Properties of UO_2 powders obtained by different routes [Henke, M., Klemm, U., Kernenergie, 23, 9a (1980) 314-318]

Parameter	ADU	AUC	Dry
Specific surface area, m2/g	2.5-6.0	3.6-6.0	2.1-3.0
Bulk density, g/cm3	1.5-2.0	2.0-2,3	0.7-1.0
Pack density, g/cm3	2.4-2.8	2.6-3.0	1.5-1.9
Flowability	Bad	Good	Good
O/U ratio	2.03-2.17	2.0-2.16	2.05-2.12
Impurity content, ppm			
F	30-50	30-70	≤100
C	40-200	120	40
Fe	≤70	10-20	10-50
Cr	40	3	20
Ni	30-40	10	6-10
Mn	5	1	2
V	10	10	1

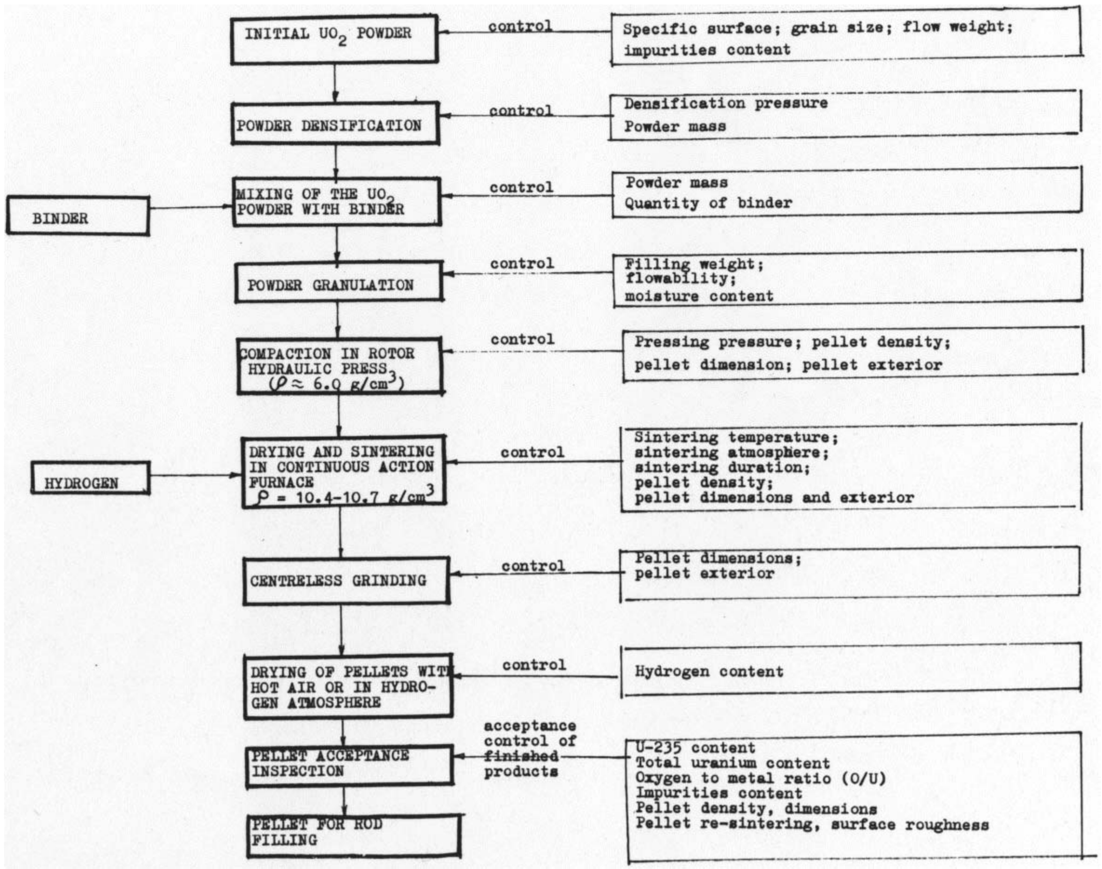
Pellet Manufacturing



Sintering and Grinding of Pellets



Technological scheme of WWER-1000 pellet fabrication in 1990's (Y. Bibilashvili, V. Onufriev, Lecture at the Training Course on Fuel QA/QC, Saclay, 1992)



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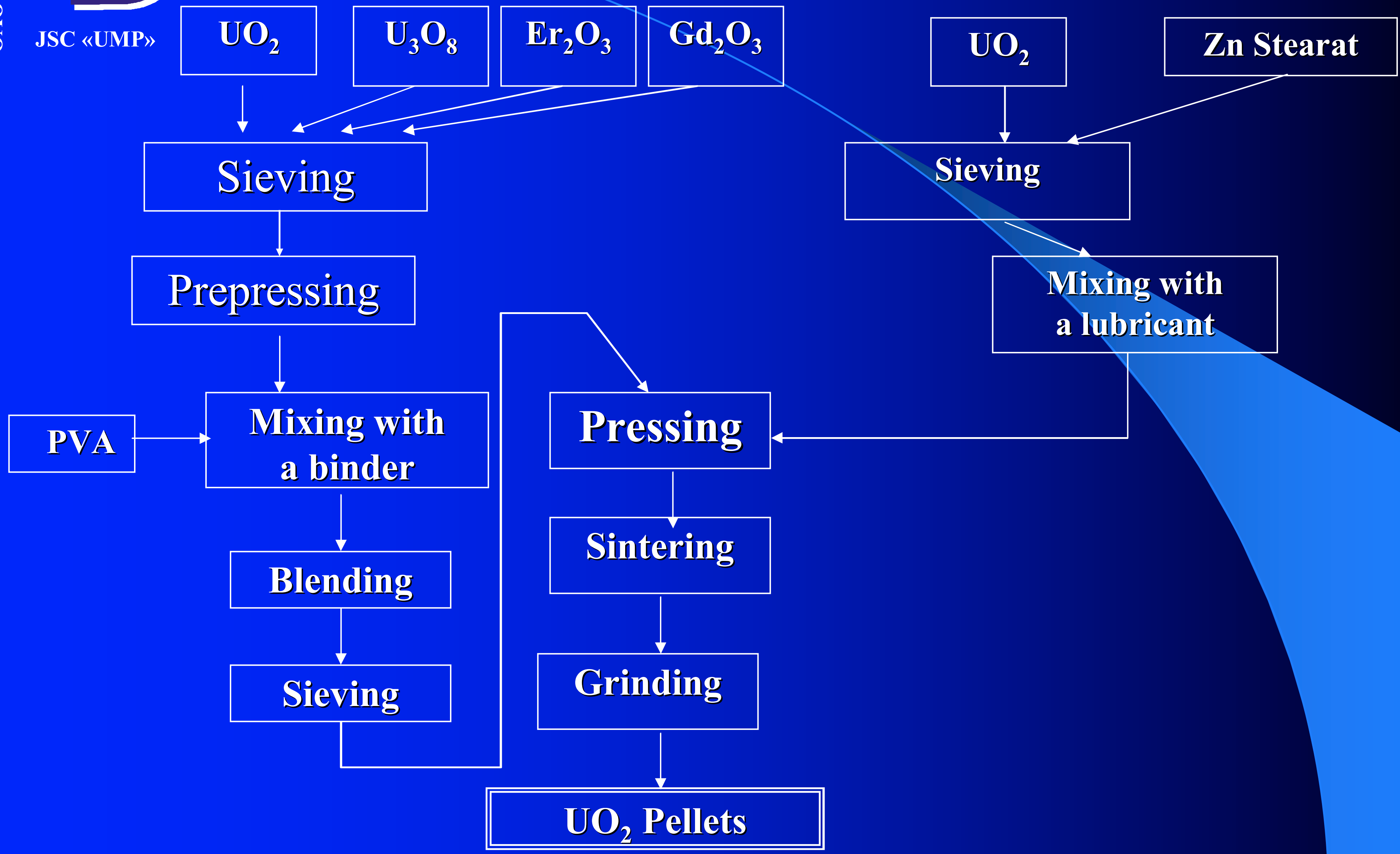
UMP -Nuclear Fuel Pellets Process flow sheet



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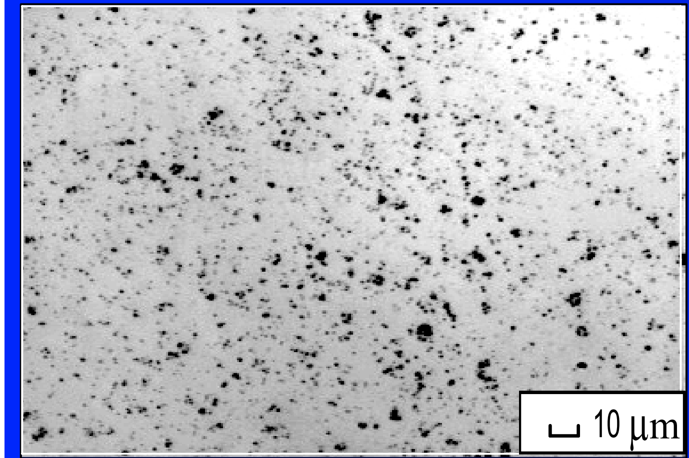
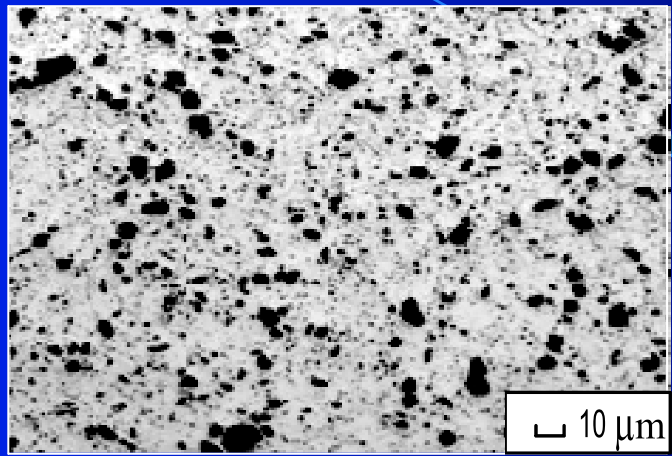
PELLET MICROSTRUCTURE OPTIMIZATION (TECDOC-1416)

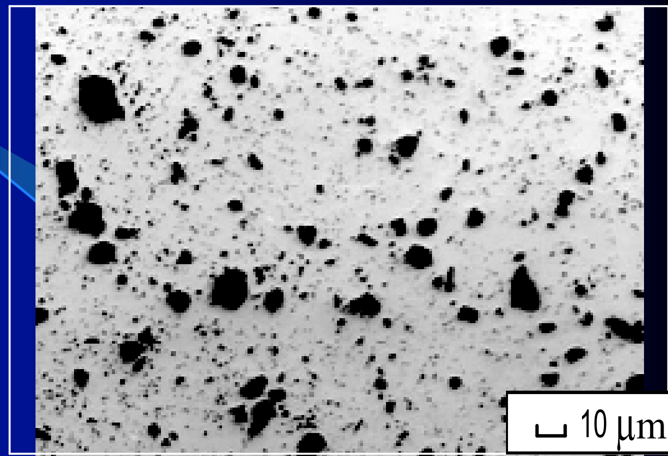
PORE MICROSTRUCTURE OF UO_2 PELLETS



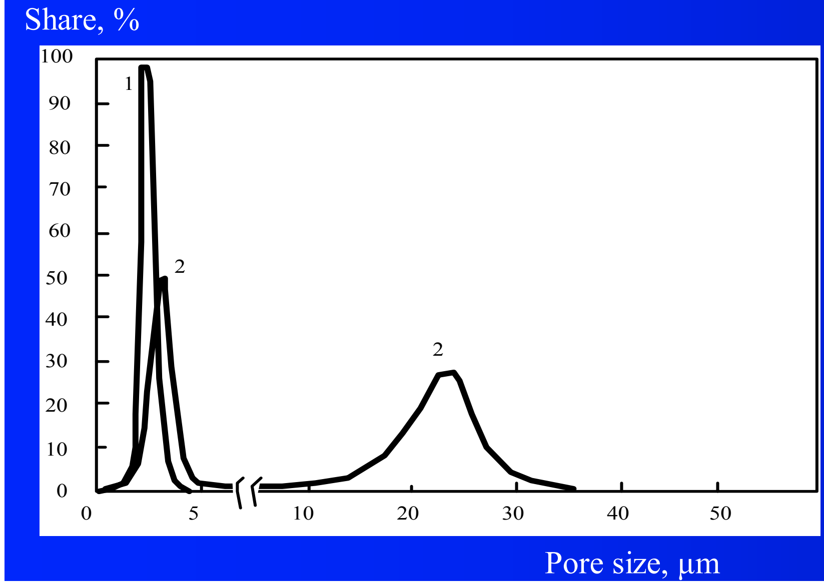
addition of pore-forming agent 0.1 wt.%



addition of pore-forming agent 0.5 wt.%



addition of pore-forming agent 1.0 wt.%



PORE DISTRIBUTION BY SIZE

1 – monomodal pore distribution;

2 – bimodal pore distribution

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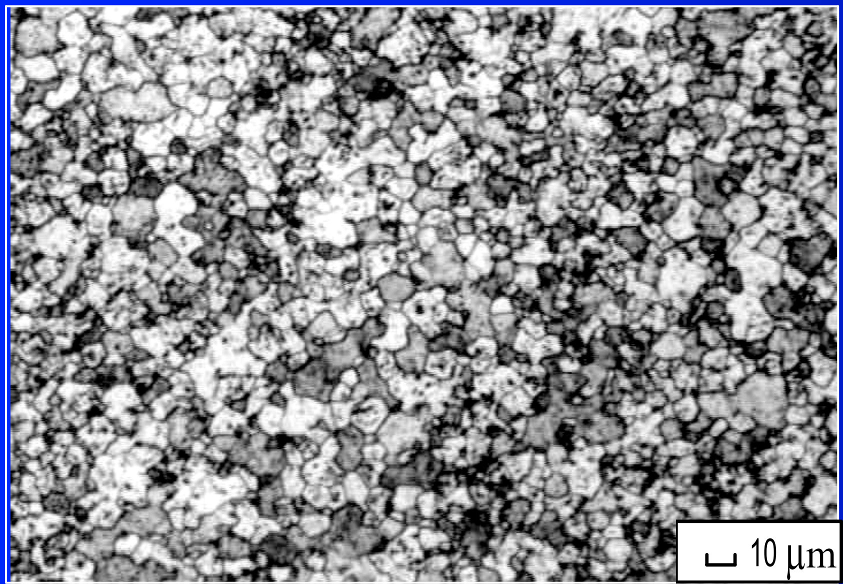
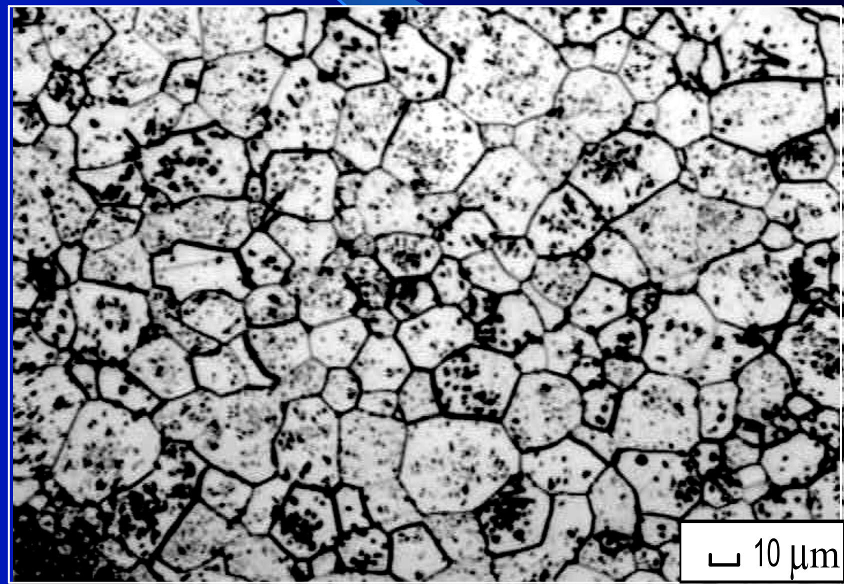
PELLET MICROSTRUCTURE OPTIMIZATION (TECDOC-1416)

MICROSTRUCTURE OF UO_2 PELLETS



Pellet of “pure” UO_2



Pellet of UO_2 alloyed with aluminum silicate admixture

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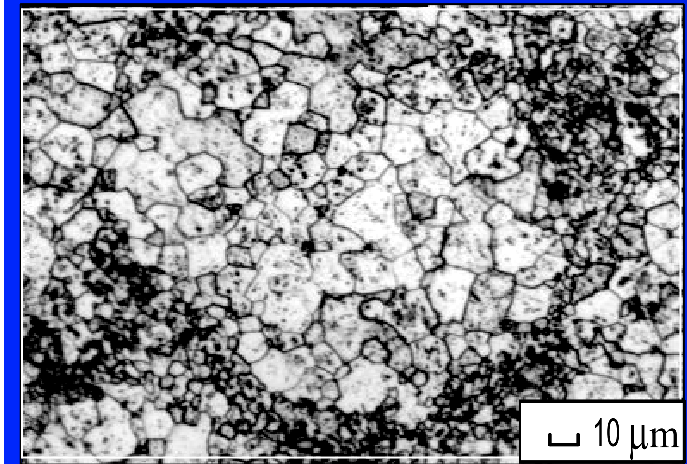
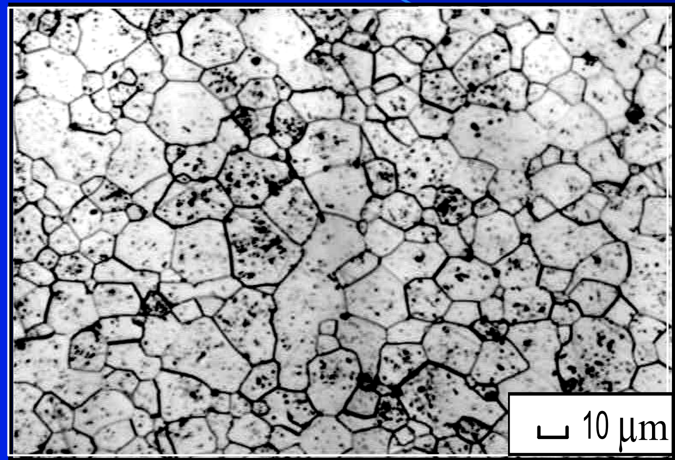
PELLET MICROSTRUCTURE OPTIMIZATION (TECDOC-1416)

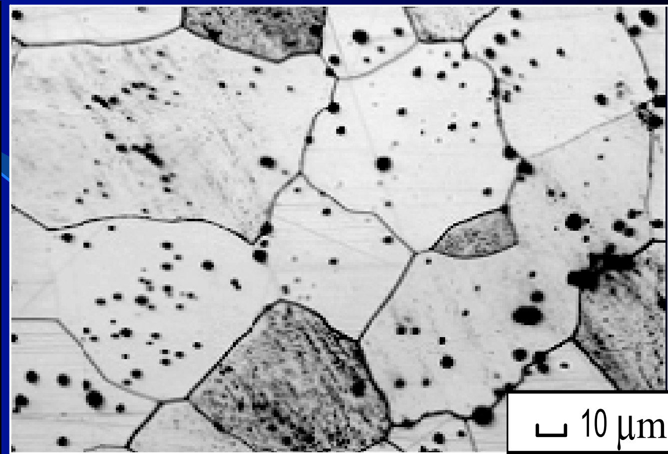
GRAIN MICROSTRUCTURE OF UO_2 PELLET



Pellet with bimodal structure

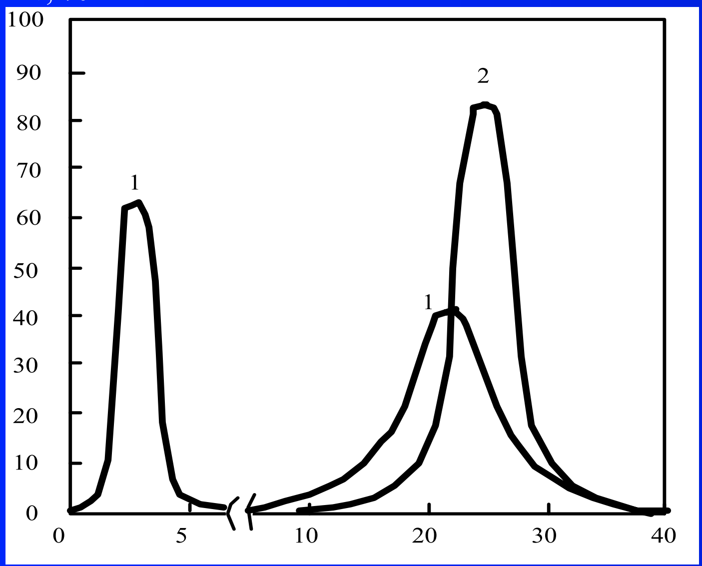


Pellet with monomodal structure
(G ~ 23 мкм)



Pellet with monomodal structure
(G ~ 90 мкм)

Share, %



Grain size, µm

GRAIN SIZE DISTRIBUTION IN PELLET

1 – Pellet with bimodal structure;

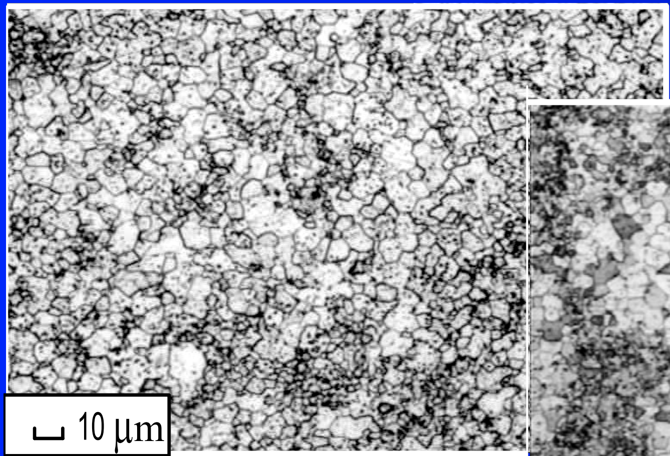
2 – Pellet with monomodal structure

ОАО «УМЗ»

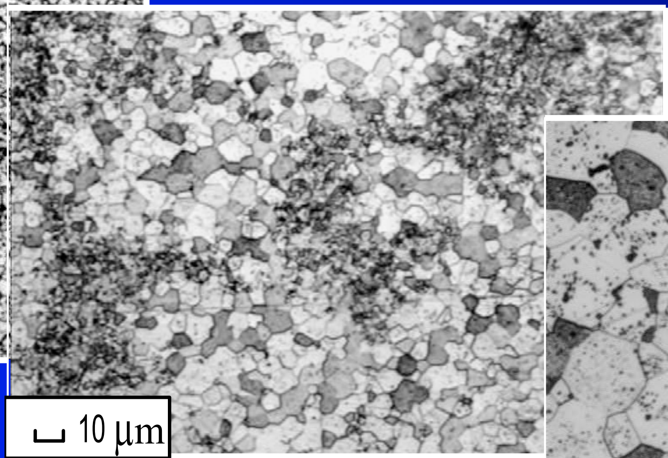
JSC «UMP»

PELLET MICROSTRUCTURE OPTIMIZATION (TECDOC-1416)

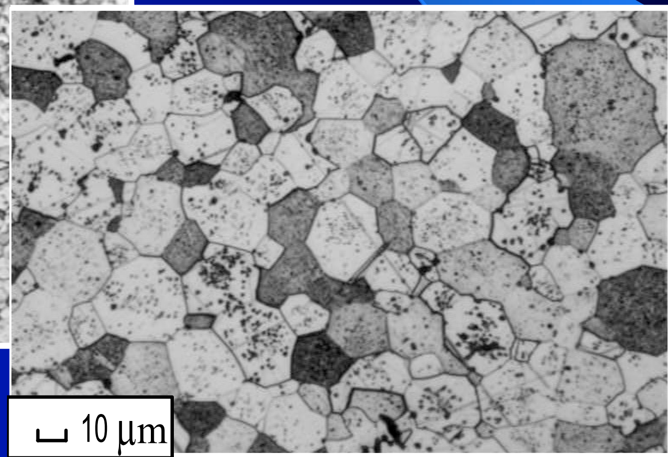
MICROSTRUCTURE OF URANIUM-GADOLINIUM FUEL



Non-optimized pellet



Pellet with aluminum silicate admixture



Pellet alloyed with aluminum silicate admixture and optimized by addition of gadolinium

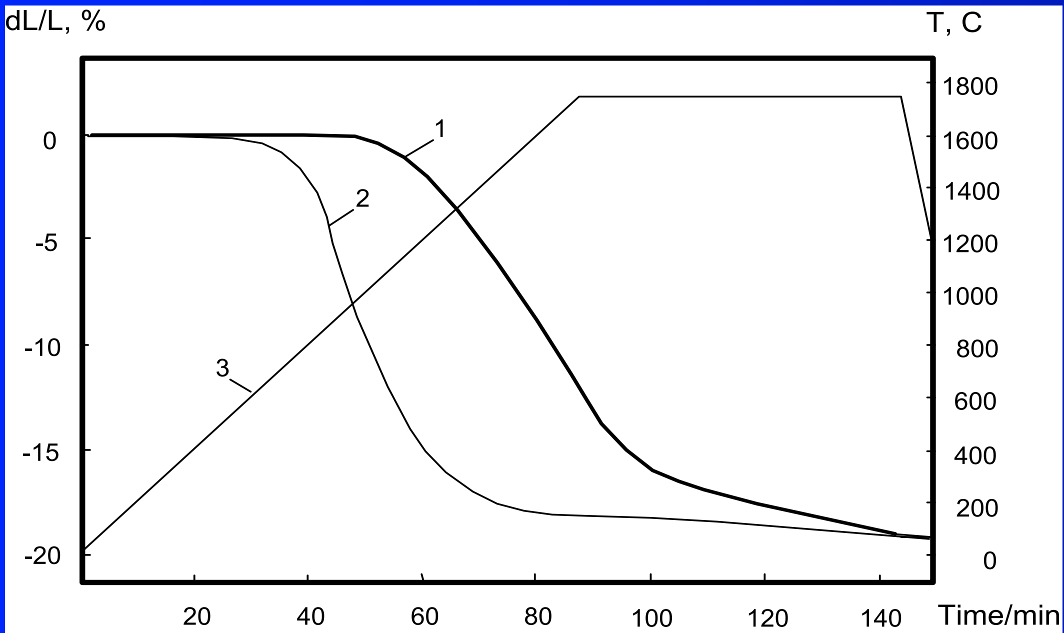
OAO «УМЗ»

JSC «UMP»

PELLET MICROSTRUCTURE OPTIMIZATION (TECDOC-1416)

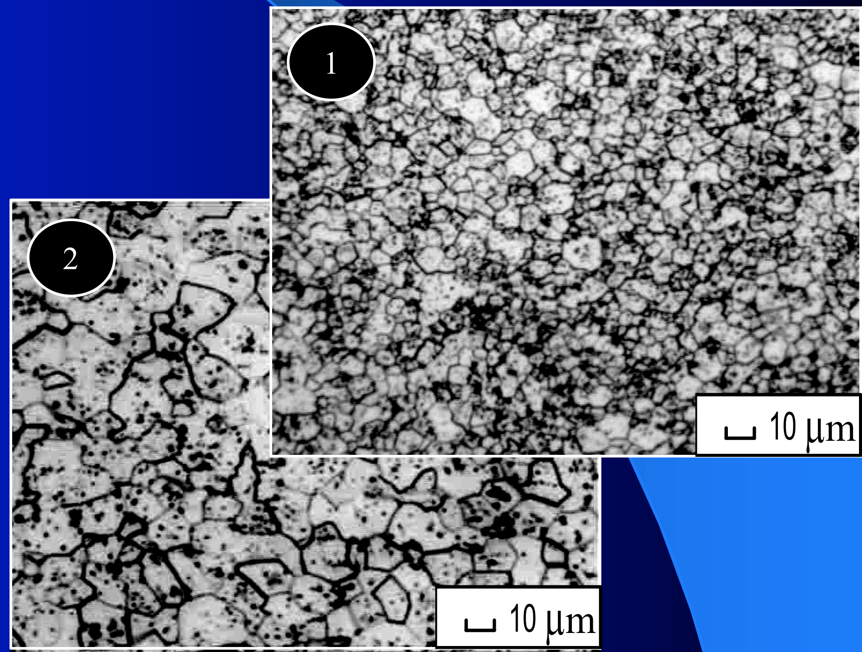
THE USE OF HIGHLY ACTIVE UO_2 POWDERS with SAV=6-8 m^2/g

PELLETS' SHRINKAGE RATE DURING SINTERING



1 – curvature of shrinkage of pellet from "usual" UO_2 powder;
2 - curvature of shrinkage of pellet from highly active UO_2 powder;
3 – curvature of pellet heating

GRAIN MICROSTRUCTURE OF UO_2 PELLETS



1 – pellet from "usual" UO_2 powder;

2 – pellet from highly active UO_2 powder

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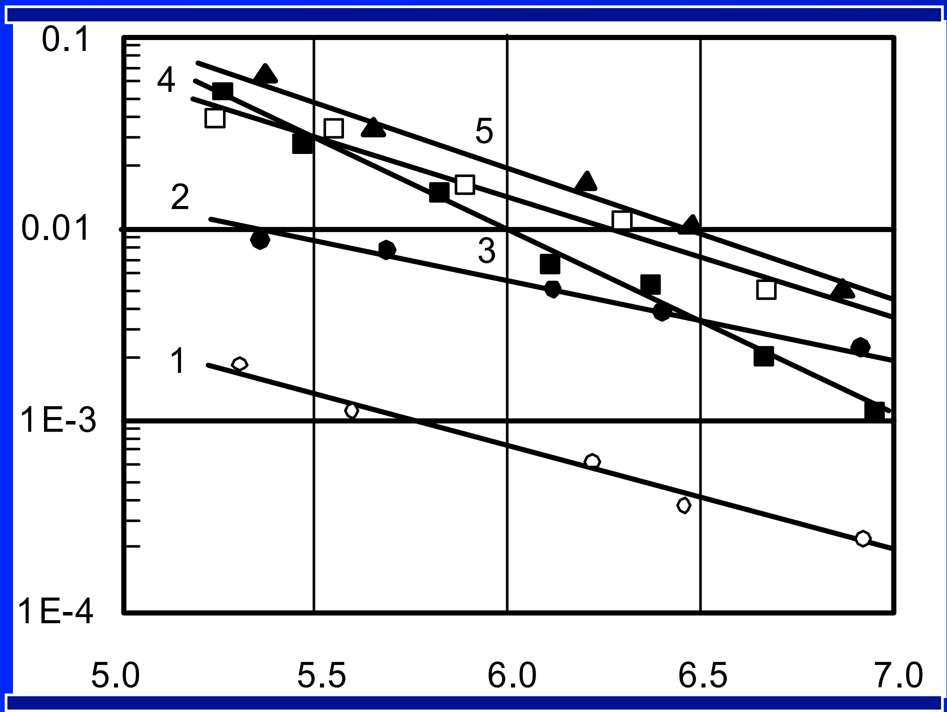
PLASTIC PROPERTIES OF FUEL PELLETS (TECDOC-1416)

Correlation of fuel pellets creep rate in the function of inverse temperature under the strain of 30 MPa

ε, 1/h



10000/T, 1/K

1 – fuel pellet from "pure" UO_2 (average grain size 13 μm);

2 - fuel pellet from UO_2 alloyed with aluminum silicate admixture (admixture concentration 0.0050 wt. %, average grain size 25 μm);

3 - fuel pellet from UO_2 with bimodal microstructure alloyed with aluminum silicate admixture (admixture concentration 0.0030 wt %, average grain size 20 μm);

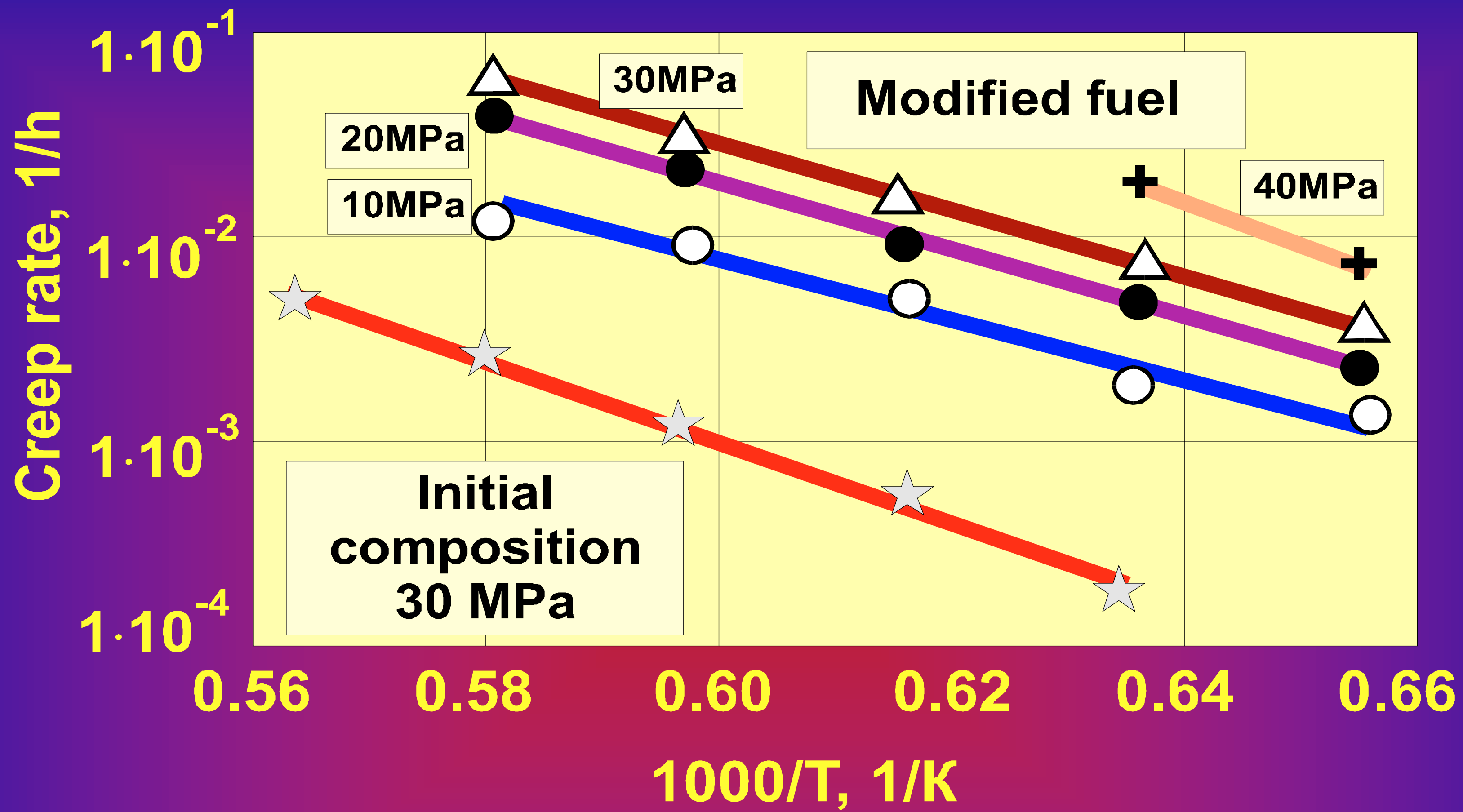
4 – fuel pellet from UO_2 alloyed with aluminum silicate admixture (admixture concentration 0.010 wt %, average grain size 30 μm);

5 – fuel pellet from UO_2 alloyed with aluminum silicate admixture (admixture concentration 0.025 wt %, average grain size 30 μm);

Characterization of Specimens Studied

Yu. Bibilashvili, IAEA TM on Improved Pellets, TECDOC-1416, 2004)

Composition	Density, g/cm^3	Grain size, μm	O/Me ratio
UO_2	10.4	11	2.0015
UO_2+ Mullite 0.25% mass ($2SiO_2$ Al_2O_3)+ Nb_2O_5 0.1% mass	10.4	16	2.0032



Creep rate of standard and modified UO_2

vs. reversed temperature:

☆ - standard pellets

○, ●, △, + - modified UO_2 at stresses 10,20,30 and 40 MPa, respectively

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OPTIMIZED TECHNOLOGIES OF FUEL PELLETS PRODUCTION AT ULBA PLANT ENSURE (IAEA-TECDOC 1416) :

- the level of open porosity not higher than 0.3% while preserving the high level of pore structure uniformity ;
- regulation of pellet density and pore distribution by size: from monomodal distribution with average pore sizes about 1.5÷3.5 μm to bimodal distribution with average pore size of small pores about 1÷3 μm and the average size of large pores about 10÷50 μm
- regulation of the average grain size and grain distribution by sizes within wide ranges: from bimodal structure with the grain size of 1÷3 μm of fine-grain phase and 10÷30 μm of coarse-grain phase to homogeneous monomodal structure with the average grain size about 20÷50 μm. At the summary boron equivalent of alloyed pellets not exceed 1.0 μg/gU
- the alternative method of grain size increase up to 25÷30 μm that is the use of highly active UO_2 powders in the production of pellets.
- high plastic properties of pellets

Summary on fuel pellet optimization

- Increase of dioxide grain size and hot plasticity by alloying with $2SiO_2 \cdot Al_2O_3$, sometimes also with and Nb_2O_5, use of powders with high Surface Area Value and controlled grain boundary porosity
- Possibility for different pore size and grain size distributions, e.g. mono-modal, bi-modal
- Decreasing diameter of the inner pellet hole for WWERs from 2.4 mm to 1.2-1.6 mm, and not excluded in future-up to O mm. Availability of facets.
- Implementation of U-Gd and U-Er Integrated Fuel Burnable Absorbers in WWERs and RBMKs, respectively

Specific features of RepU (Reprocessed U) pellet fabrication for RBMKs and WWERs at Ulba plant-Proselkov V., et al, IAEA-TECDOC 1416, p. 69

- Fabrication of RepU fuel pellets for RBMK-1000s started in 80s
- To check the possibility of the use of RepU fuel in WWER-440 reactors six FAs were fabricated for the experimental operation. The fuel composition was the following: U-235 –2.4%. U-236 – 0.45%. The compensation for U-236 was not carried out. The FAs with RepU were installed into the Kola NPP-Unit 1 for the 21st fuel campaign.
- The batch of WWER-1000 pellets was also produced with comp. U235 level of 4%, 18 TVSA loaded into Kalinin-2 (17^{th} campaign)
- The analysis of experimental operation results revealed that the neutronic and thermal-physical properties of RepU fuel assemblies used in the Kola NPP practically fully corresponded to those for the normal uranium fuel assemblies.

Technological scheme of ADU-process for RepU pellet fabrication at Ulba plant- Proselkov V., et al, IAEA-TECDOC 1416, p. 69

- separate dissolving of the uranyl-nitrate fusion cake from spent WWER-440 fuel (U-235 content - 0.8 – 1.2%) and medium-enriched RepU (U-235 content - 14 - 17%) monoxide-oxide in nitric acid;
- mixing the two solutions in a ratio ensuring production of the solution with the actual U-235 content - 4.139% (for WWER-1000);
- extraction and re-extraction of the produced solution for removing impurities;
- treatment with aqueous ammonium solution for precipitation of ammonium polyuranate;
- filtration of precipitate, drying and calcination;
- reduction of uranium monoxide-oxide in hydrogen;
- specific check of U isotope’s content

View on fuel fabrication practices and plans

- Electrostal plant (~60% of fuel fabrication in Russia):
  - dry conversion was implemented in 90's;
  - Wet route-for treatment of reused materials;
  - New 400 t/a dry conversion route powder shop was commissioned jointly with Siemens in 2003; total conversion capacity is ~1500 t/a
  - Separate lines for WWER, PWR and BWR rod fabrication in 2004;
  - Shops for fabrication of U-Gd and U-Er oxide fuels;
  - New designs for WWER and RBMK rods/assemblies.

View on fuel fabrication practices and plans

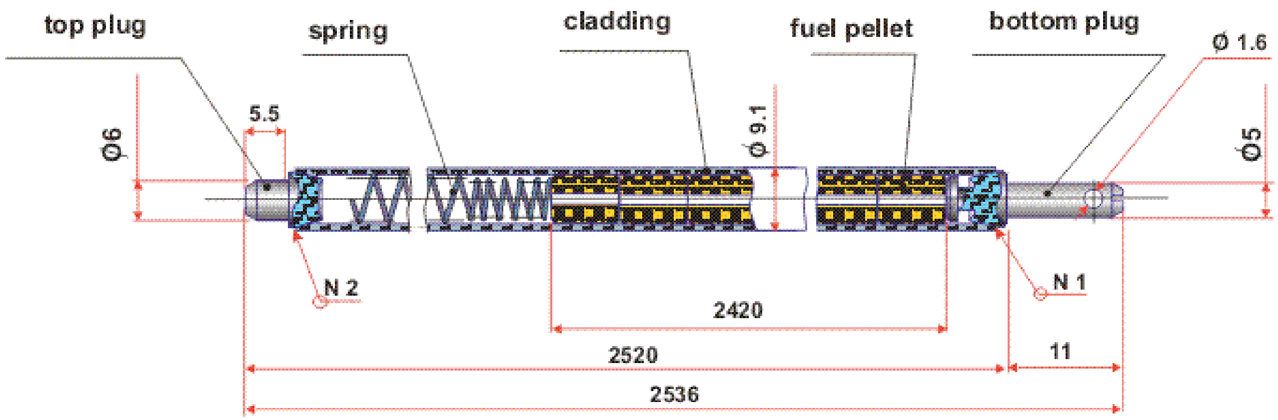
- Novosibirsk plant (~40% of fuel fabrication in Russia): :
  - Initially plant was destined for rod and FA fabrication with importing WWER-1000 pellets from Ulba plant
  - In 2001 wet conversion shop (~50 t/a) was completed for reused materials treatment;
  - In 2003 wet conversion shop (~150-200 t/a) was completed for WWER powders/pellets;
  - Dry conversion shop (450-600 t/a) is under construction
  - Separate lines for WWER, PWR and BWR rod fabrication in 2004/05;
  - New designs for WWER rods/FAs.

Zr alloy/tubing production in Russia

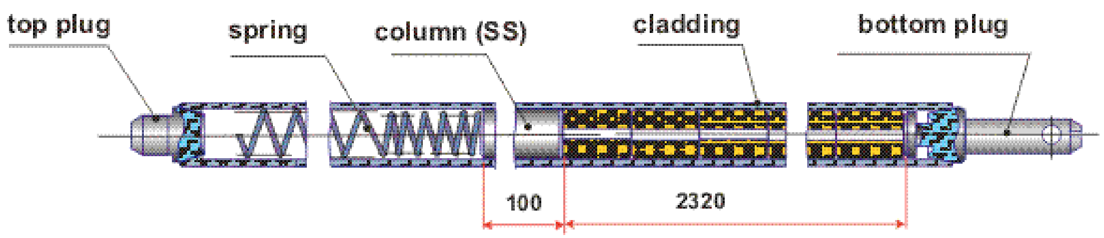
- Zr alloys/tubings are produced at the JSC Chepetsk Mechanical Plant, Glazov, Udmurt Republic
- Zr powder is now produced by electrolysis with subsequent iodine refining
- Zr sponge fabrication technology/equipment is in the final implementation/mounting stage
- Extraction-rectification separation of Zr and Hf allows Hf content rather lower 100 ppm in finished clads
- E-110 (Zr-1%Nb) and E635 (Zr-Sn-Nb-Fe) are present clad alloys and E-125 (Zr-2.5%Nb) is present pressure tube alloy

WWER-440 Fuel Rod Design

FUEL ROD OF WWER-440 FUEL ASSEMBLY



FUEL ROD OF WWER-440 CONTROL FUEL ASSEMBLY

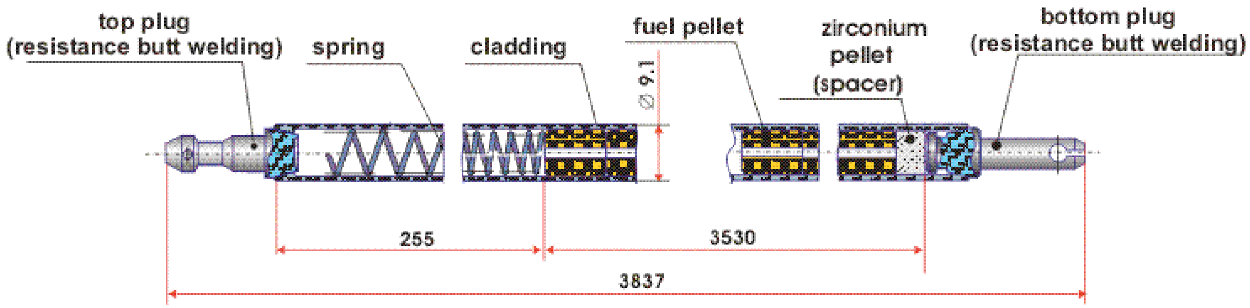


Changes in Major Parameters of WWER-440 Working Fuel Assembly

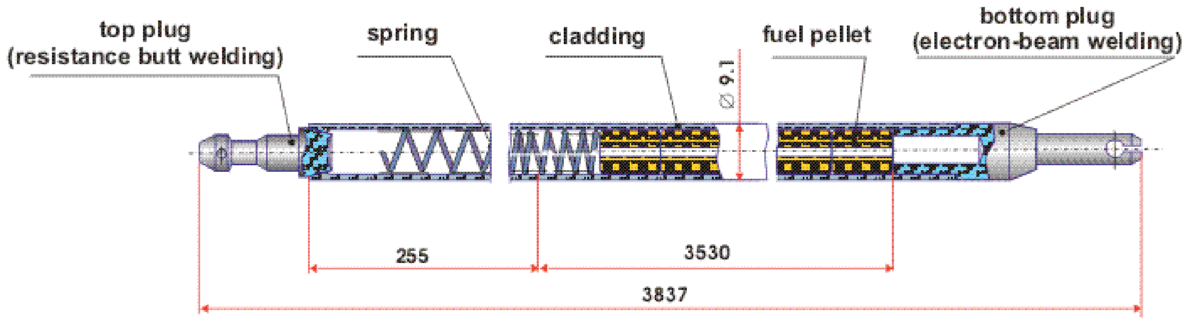
Parameter	Design	
	Standard	Second generation fuel (U-Gd)
Assembly		
Fuel rod pitch in bundle, mm	12.2	12.3
Central hole diameter of fuel pellet, mm	1.4	1.2
Outer diameter of fuel rod, mm	9.1	9.07
Outer diameter of pellet, mm	7.57	7.60
Fuel column length,mm	2420	2480
Hf content of Zr materials, % mass	0.05	0.01

WWER-1000 Fuel Rod Design

WWER-1000 fuel rod and U-Gd-fuel rod
(manufacturer - Electrostal fabrication plant)



WWER-1000 fuel rod and U-Gd-fuel rod
(manufacturer - Novosibirsk chemical concentrate plant)



Evolution of VVER-1000 FA Design

Phenomena of FA bow and Incomplete control Rod Insertion (IRI) were first observed in 1993-94 in some WWER-1000s and PWRs with long cores pushed designers to improve stiffness and rigidity of FA's skeleton. These measures included:

•Increase of RCCA gravity weight

•More rigid Guide Tubes (thickness increase and more resistant material)

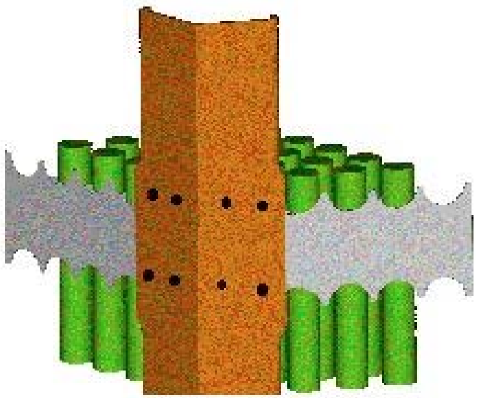
•Better rod and GT consolidation in the spacer grid (SG); new SG design Better fixation of the SGs on central tube, etc….

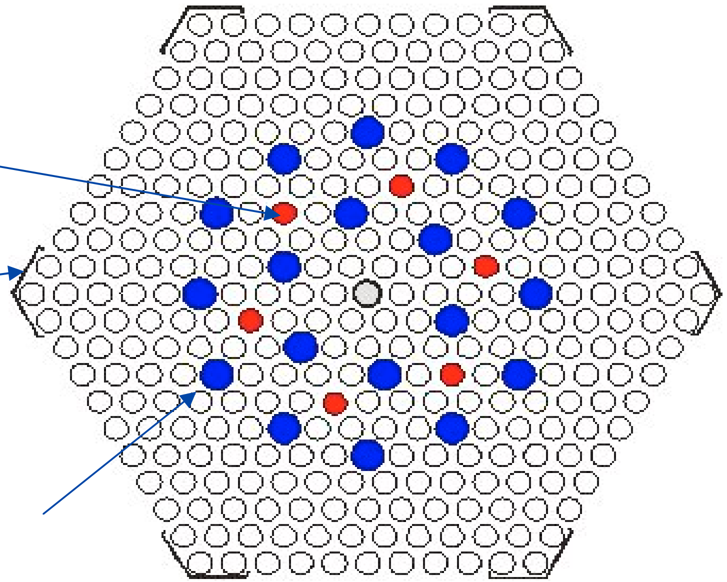
Non-FA bow related improvements included debris filters and possibility to dismantle the bundle. For WWER-1000 there were developed two novel FA designs:

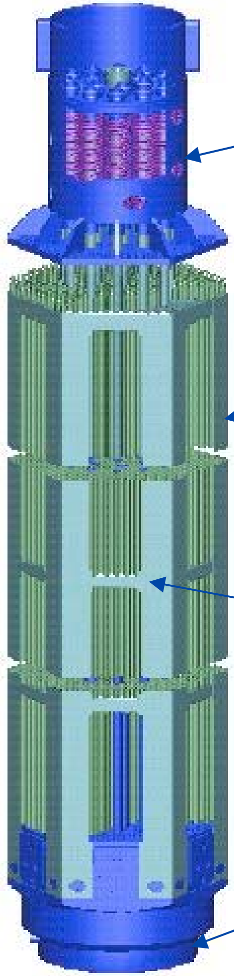
•TVSA (developed by OKBM, Nizni Novgorod) and

•TVS-2 (developed by OKB "Hydropress", Podolsk, Moscow region).

Design of TVSA







By V. Novikov-Technical Working Group on Water Reactor Fuel Performance and Technology (TWGEPT IAEA), 2005

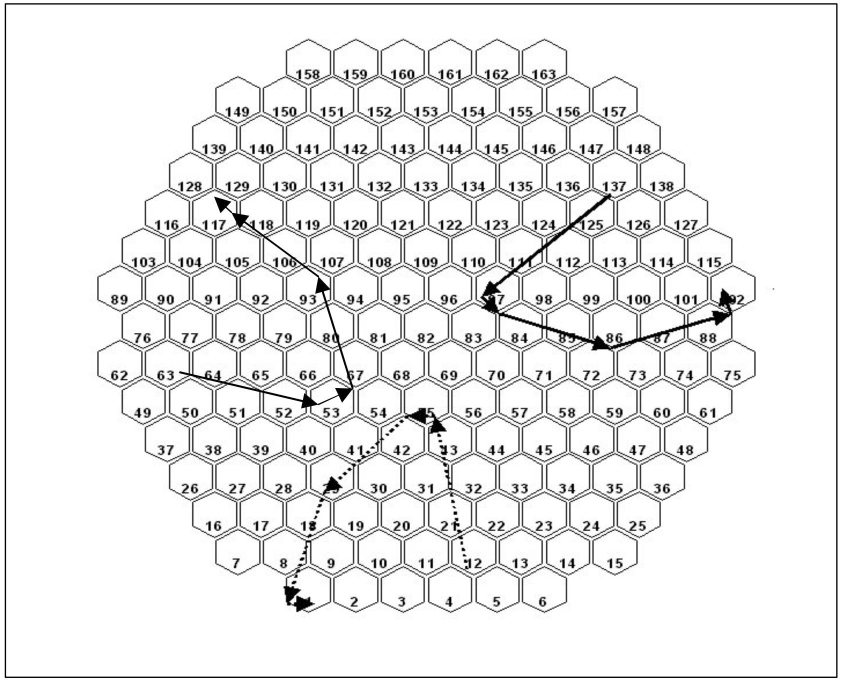
2.2.The results of the TVSA operation in unit N1 of the Kalinin NPP.

Beginning from 2002 the core of unit 1 is fully loaded with TVSA. The result of TVSA operation in unit 1 of the Kalinin NPP:

- **The core straightening is assured: the inter-assembly gaps of ~4 mm, saggings of ~4 mm, which allowed a substantially higher rate of the TVSA transfer during reloading and TPRO and the reloading time to be shortened by 4-6 days;**
- **The problems inherent in the Control Rod jamming dropping time and pulling forces have been obviated. The testing results are favourable;**
- **12 TVSA were tested for 5 years, 2 TVSA were tested for 6 years;**
- **The maximal fuel burnup per TVSA is ~56 MW·day/kg U, per fuel rods is ~66 MW·day/kg U after a six year operation.**

Schematics of TVSA motion

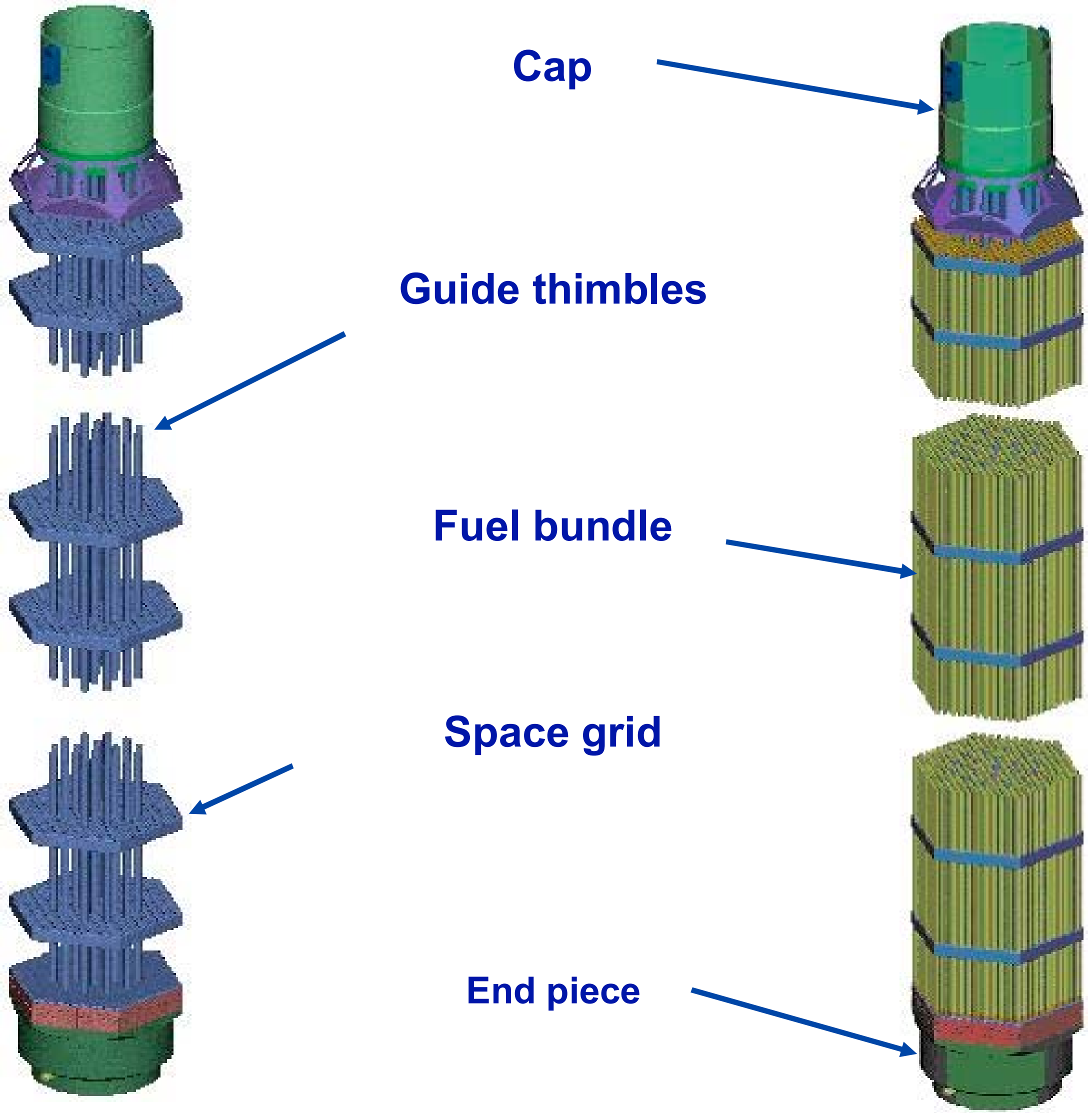
(left in the 20th load of the 1st unit of the Kalinin NPP for the 6th operation year during 2004-2005)



- 2 TVSA with fuel clad in E110 alloy

- 1 TVSA with fuel clad in E635 alloy

Design of TVS-2

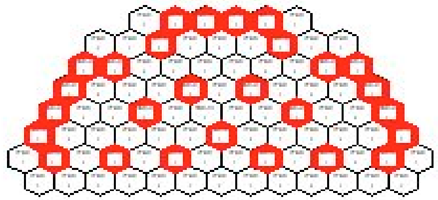


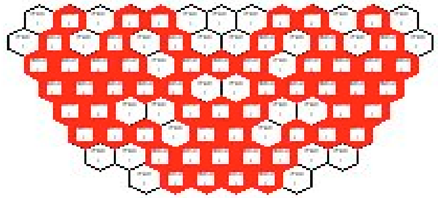
By V. Novikov, Technical Working Group on Water Reactor Fuel Performance and Technology (TWGEPT IAEA), 2005

TVS-2

In 2003 in the frame of the programme of increasing capacity factors the core of unit N1 was loaded with the first batch of TVS-2. The favourable results of the pilot operation allowed the extended loading of the unit and the introduction of TVS-2 into the other units of the Balakovo NPP.

Cartogram of the 13th fuel loading



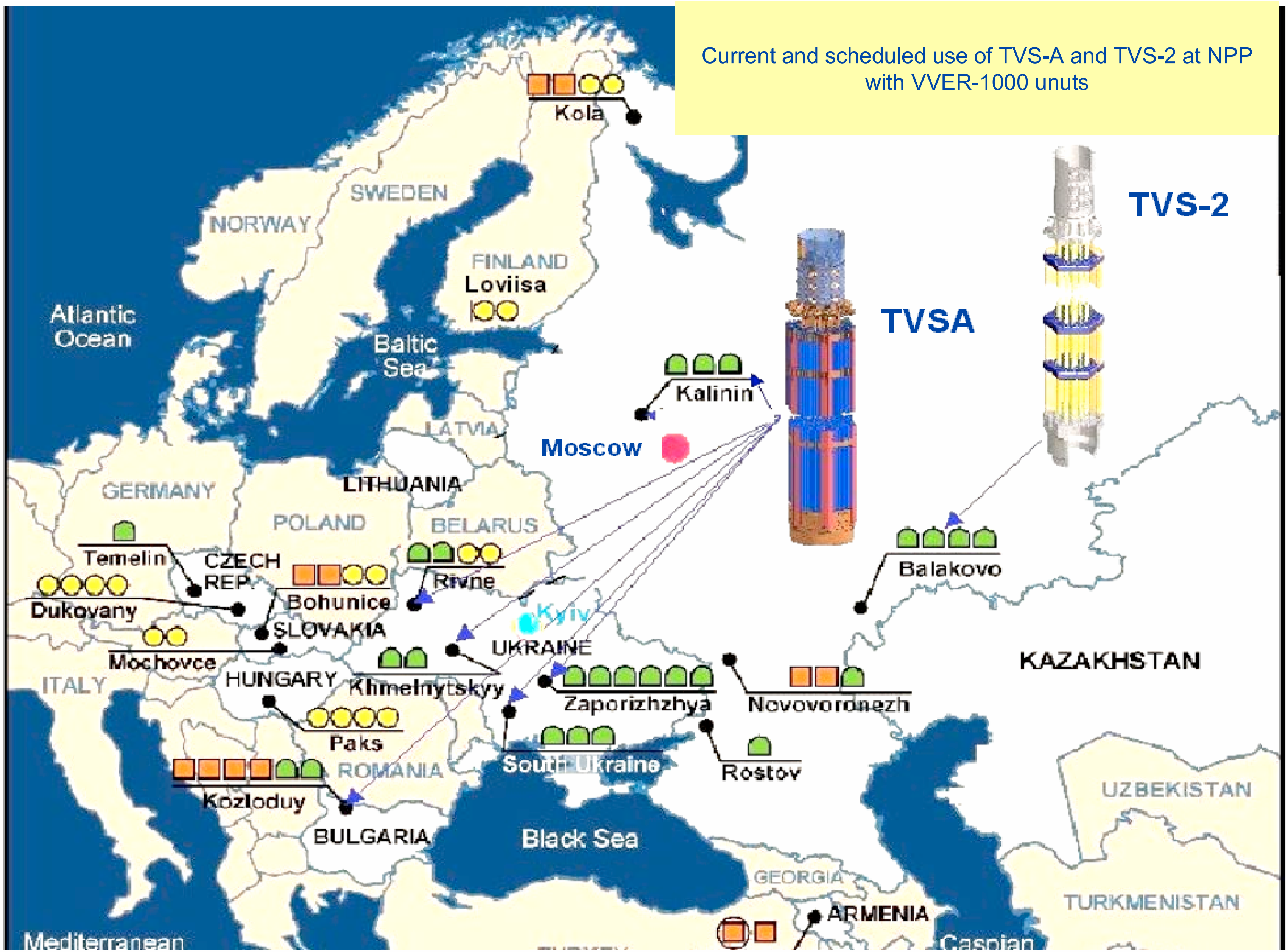


Cartogram of the 14th fuel loading

Table 3

Unit N	Fuel load	Loading date	Quantity of TVS-2 loads		Mean fuel of enrichment	Quantity of U-Gd fuel rods/fuel enrichment / Gd_2O_3 content	Cycle length, eff.days	Burnup, MW·day/kg U		
								After 1 load.	After 2 load.	After 3 load.
1	13	29.03.03	54	18	3.53	9 / 3.3 / 5	363	14.1 - 19.3	-	-
				12	4.30	6 / 3.6 / 5				
				24	4.30	9 / 3.6 / 5				
	14	18.05.04	54	18	3.90	9 / 3.3 / 5	367	14.4 - 20.2	31.4 - 35.2	-
				36	4.30	6 / 3.6 / 5				
	15	forcast	55	19	3.98	9 / 3.3 / 5	379	14.7 - 20.8	33.1 - 37.3	39.7 - 50.2
				24	4.38	6 / 3.6 / 5				
				12	4.38	9 / 3.6 / 5				
2	13	27.06.04	54	18	3.53	9 / 3.3 / 5	289	10.5 - 15.6	-	-
				36	3.90	9 / 3.3 / 5				
3	13	22.10.04 –	54	18	3.53	9 / 3.3 / 5	351.9	13.7 - 18.3	-	-
				12	4.30	6 / 3.6 / 5				
				24	4.30	9 / 3.6 / 5				

Current and scheduled use of TVS-A and TVS-2 at NPP with VVER-1000 unuts



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