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Description of Fresh and Spent Fuel Storage at Balakovo NPP—Definitions for Safety Calculations

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Russian Research Center “Kurchatov Institute”

A Russian Contribution to the Fissile Materials Disposition Program

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*Joint U.S. / Russian Project to Update, Verify and Validate
Reactor Design/Safety Computer Codes
Associated with Weapons-Grade Plutonium Disposition in VVER Reactors*

Description of Fresh and Spent Fuel Storage at Balakovo NPP.
Definitions for Safety Calculations

Report

General Order 85B-99398V

Project Manager

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ACRONYMS

BV - cooling pool (non-compact)
EFPD – effective full power day
FA - fuel assembly
HM - heavy metal
MOX - mixed uranium-plutonium fuel
NPP - nuclear power plant
UBV - compact cooling pool
UOX - uranium-oxide fuel
VVER - Russian water-water reactor

ABSTRACT

The document issued according to **Work Release KI-WR04RTP. P. 00-6B** presents means of fuel storage and transportation used in Russian VVER-1000 NPPs, the models for their nuclear and radiation safety calculations and describes the set of regimes to be calculated according to Russian safety requirements.

CONTENT

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Tables

1. Means for transport and storage of fresh and spent fuel at VVER-1000 NPP

Principal scheme of fuel transportation at VVER-1000 NPP and particularly at Balakovo NPP [1] is shown in Fig.1. Fresh fuel assemblies are transported from the production plant to NPP by means of the railway in special package sets. The package set consists of two tubes positioned in parallel and welded on to the interlayer. The ends of the pipes have nozzles hermetically covered by removable lids. There is a wooden container in the each tube that holds the fuel assembly. The package set is intended for two FAs location.

Storage of uranium FAs at NPP Fresh Fuel Depository is performed either in package sets stacks or in decks or in the covers for fresh fuel. MOX fuel storage is supposed to perform only in package sets avoiding an excessive radiation in comparison with other types of storage.

Fuel assembly transport from the fresh fuel depository to the reactor hall is performed in the covers for fresh fuel. The cover for fresh fuel is intended for transport of 18 fuel assemblies placed vertically. Fuel assemblies may be loaded from the cover directly into a reactor or into a cooling pool.

The cooling pool is intended for holding the irradiated fuel assemblies during the time necessary for decrease of the residual heat to the values, which allow transportation of spent fuel from NPP. According to the base Technical project of VVER-1000 NPP, the FAs are placed in non-compact decks. The cooling pool sub-criticality is ensured by the choice of their positioning pitch in the water. This type of positioning of fuel assemblies provided 3 years storage of irradiated fuel assemblies and possibility for emergency unloading of the core at any moment. Recently cooling pools at some VVER-1000 units have been modernized (for example Balakovo 4) by means of the decks for close or compact fuel storage (SUHT) with the use of hexagonal tubes made of borated steel. Such technical decision, which realizes the principle of combined neutron "trap", increased the storage capacity of the decks' lattice 1.8 times and provided sub-criticality for uranium fuel in the accidental regimes while coolant density decreasing. It should be mentioned that the increase of cooling pool capacity is favorable for MOX fuel because its use demands more long exposition to lower residual heat generation till the values acceptable for MOX FAs transportation from NPP.

After necessary exposure in a cooling pool, spent fuel is transported from NPP by railway in the transport containers TK-13. Such containers are intended for 12 spent fuel assemblies' transport.

2. Nuclear Safety

2.1 Initial data and approaches

Main characteristics of UOX and MOX FAs are chosen according to the estimations of the Kurchatov Institute for VVER-1000 fuel cycles with 1/3 MOX core with integrated uranium-gadolinium burnable poison rods. Maximal enrichment on U-235 of UOX FAs is equal to 4.08%. Isotopic composition in MOX fresh fuel is shown in Table 2.1. Zr is used as a FA construction material, UOX and MOX fuel pins weight is 1.575 kg. 6 and 18 pins with uranium-gadolinium fuel are placed correspondingly in UOX and MOX FAs.

According to the requirements of "Safety rules for nuclear fuel storage and transport at the nuclear engineering object" [2] the following conservatism is adopted in nuclear safety calculations:

- Fresh UOX and MOX FAs are considered without integrated burnable poisons in FAs;
- Pu^{239} content is increased, Pu^{240} one is decreased in comparison with MOX FA base contents;
- Pu^{241} is taken into account by additional increase of Pu^{239} content;
- Water distributions, leading to maximal effective multiplication factor in the means of transport and storage, are considered; it should be noted that main accidental situations with a water density redistribution are to be defined as a result of calculational analysis.
- Zero boron concentration in water is considered;
- As a rule infinite fuel systems without leakage are considered;
- Auxiliary steel construction elements with strong neutron absorption are not considered.

Taking into account the above-mentioned, the conservative options of UOX and MOX FAs design have been defined (See Table 2.2) for nuclear safety calculations in the means of transport and storage.

According to the "Safety rules..." [2] the **effective multiplication factor** in the means of transport and storage during normal operation and in accidental regimes **is limited by the value 0.95**.

Table 2.1 Isotopic composition in fresh MOX fuel with U-Gd BPRs

Isotope	U-235	U-238	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
Wt. %	0.388	96.128	0.005	3.195	0.228	0.041	0.015

Table 2.2. Main FA characteristics in nuclear safety calculations

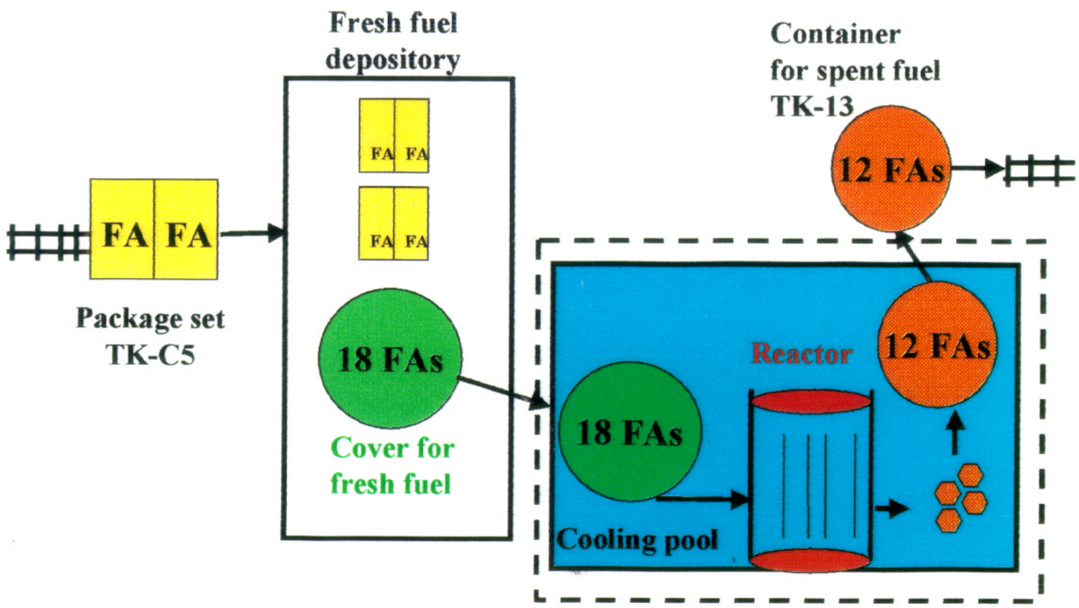
Characteristic	Value	
	UOX FA	MOX FA
Width across flats, mm	234	234
Number of fuel pins (rods) in FA, items	312	312
Number of uranium-gadolinium burnable poison rods in FA, items	-	-
Pitch between rod and rod, mm	12.75	12.75
Number of guide channels for control rods, items	18	18
Number of space grids, items	15	15
Material of space grids, guide channels and central tubes	Zr+1%Nb	Zr+1%Nb
Rod cladding diameter, mm	9.1x0,69	9.1x0,69
Diameter of guide channels, mm	13.0x1.0	13.0x1.0
Diameter of central tube, mm	13.0x1.0	13.0x1.0
Height of fuel column, mm	3530	3530
Contents of U-235 in the fuel, %	4.400	0.200
Contents of Pu-239 in the fuel, %	-	4.200
Contents of Pu-240 in the fuel, %	-	0.175
Contents of Pu-241 in the fuel, %	-	-
Mass of fuel in rod, kg	1.575	1.575

2.2 Criticality in facilities for fuel storage and transport

2.2.1 Package set

Package set containing two FAs is shown in Fig.2. His calculational model is given in the Fig 3. Cell vertical dimension is 550 мм, horizontal one is 620 мм. In axial direction model cell size is infinite.

Fig.1. Transportation scheme at VVER-1000 NPP



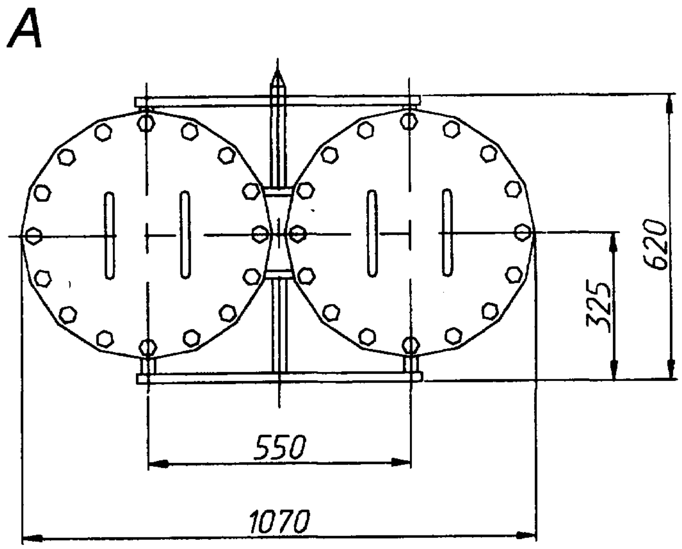


Fig.2 Package set for fresh fuel

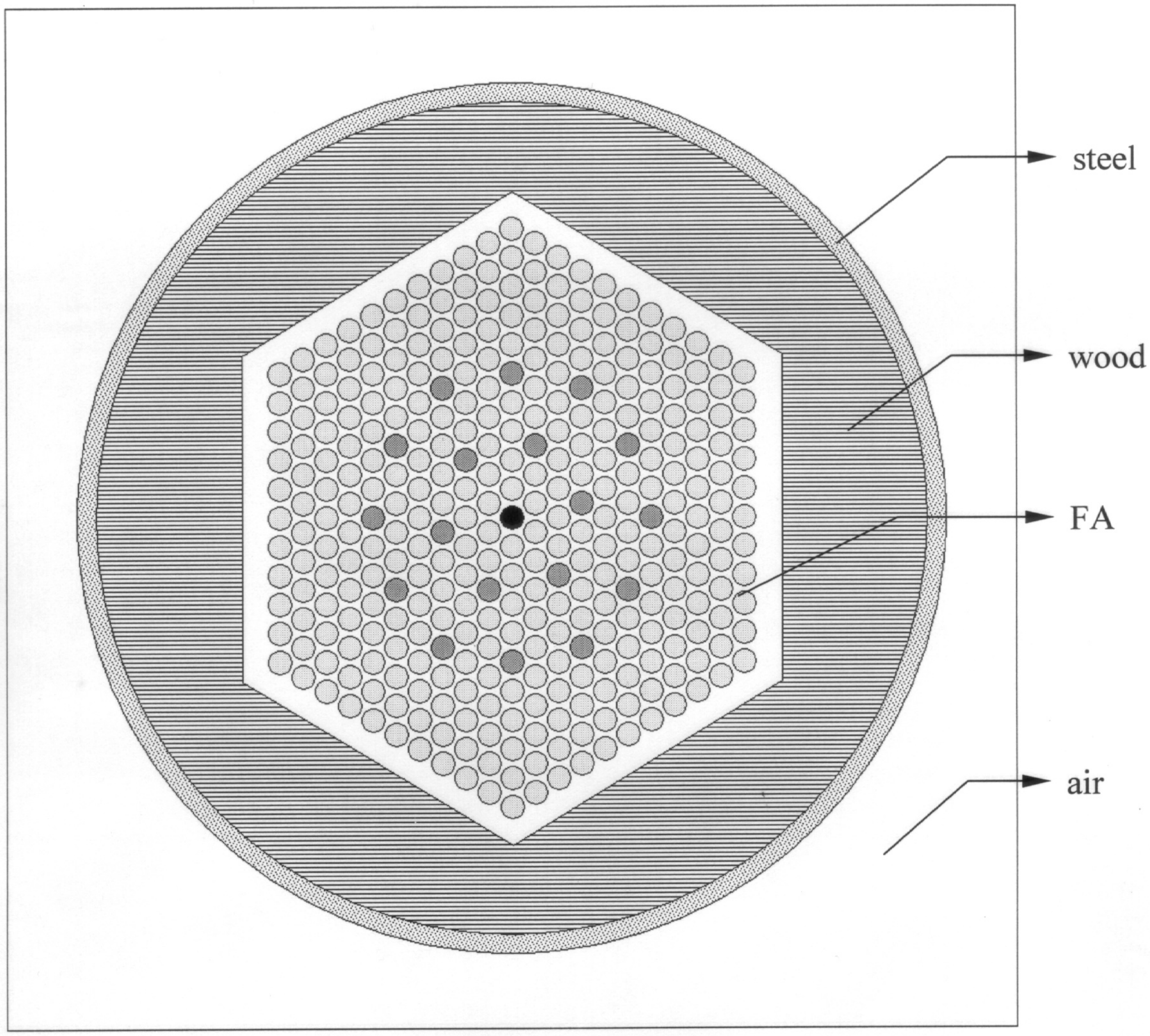


Fig.3 Calculational model of package set cell

2.2.2 Cooling pool

Calculational models for both closed (compact) and non-closed (non-compact) cooling pool are given in Fig.4. Infinite grid of cells is considered in calculations to ensure, according to "Safety rules…" [2], conservative estimation of maximal design capacity of storage and of radial reflector influence. In axial direction a calculational model dimension has been supposed unlimited. except of some cases mentioned in the text.

Dependence of the effective multiplication factor on placement pitch of UOX and MOX fuel assemblies in compact and non-compact cooling pools is to be obtained. Coolant density corresponds to a cold state, boron acid in current is absent.

Design cell dimensions of compact and non-compact cooling pools are correspondingly 300 and 400 mm. The characteristics of the compact cooling pool model are shown in Table 2.3.

Effective multiplication factors both for compact and non-compact cooling pools are to be obtained for water density interval 0-1.0 g/cm^3 (simulation of accident situation). Axial leakage influence is to be estimated.

Table 2.3. Characteristics of the compact cooling pool model

Parameter	Value
Assembly-by-assembly pitch, mm	300
Hexagonal tube width across flats, mm	257
Hexagonal tube thickness, mm	6
Gap between a fuel assembly and an inner tube surface, mm	5,5
Hexagonal tube material	Boric steel
Natural boron content in a tube material, % Wt.	1,5
Boron-10 content in a natural isotopic composition, atoms %.	19,8

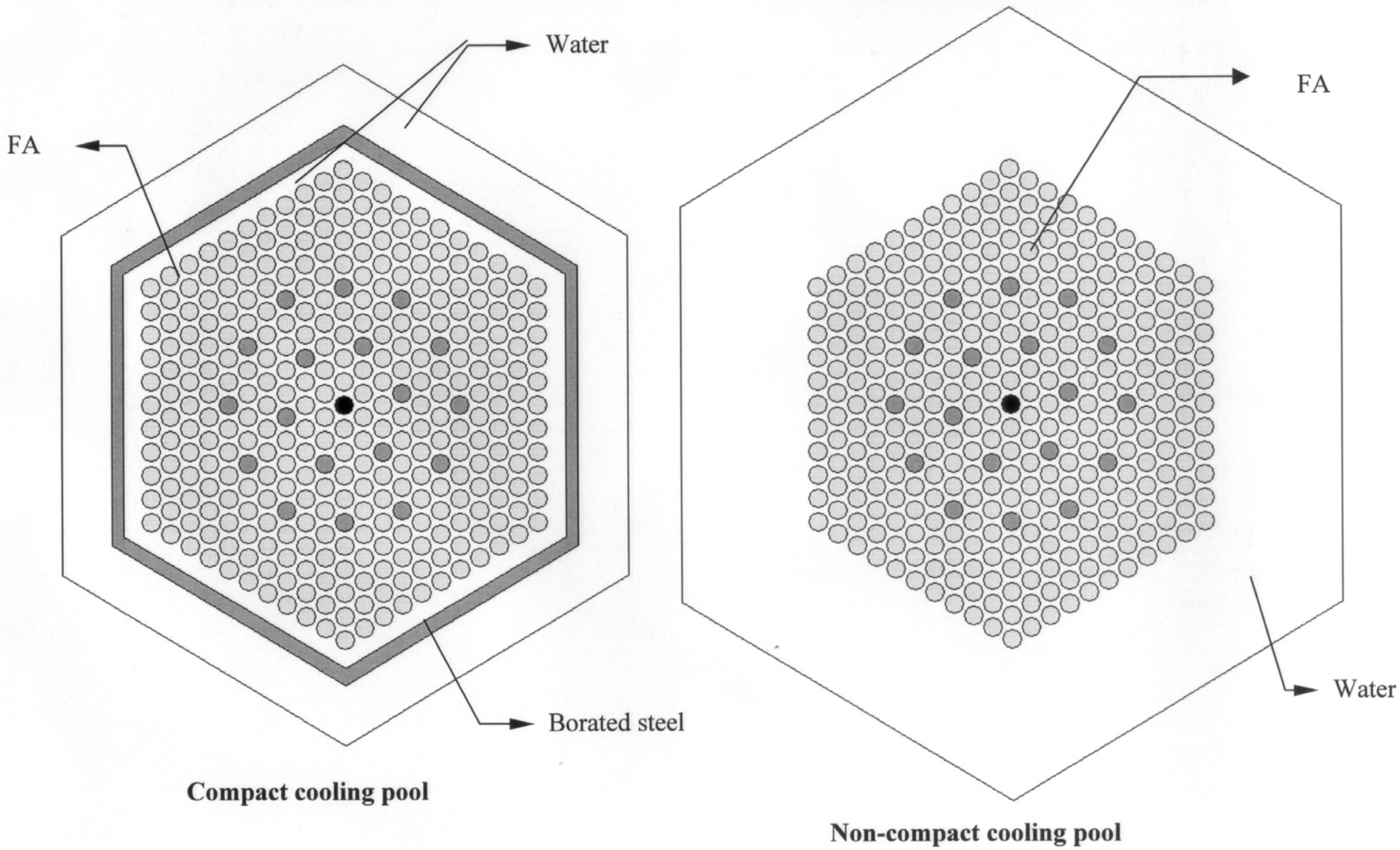


Fig.4 Calculational cell models for compact and non-compact cooling pools

2.2.3 Cover for fresh fuel assemblies

Cover for fresh FAs, schematically shown in Fig.5, is intended for FAs storage and transport at NPPs. 18 fresh FAs are positioned in a cover with a pitch of 400 mm corresponding to the pitch in a non-compact cooling pool. A scheme of fresh fuel transportation from a cover to a reactor is shown in Fig.6.

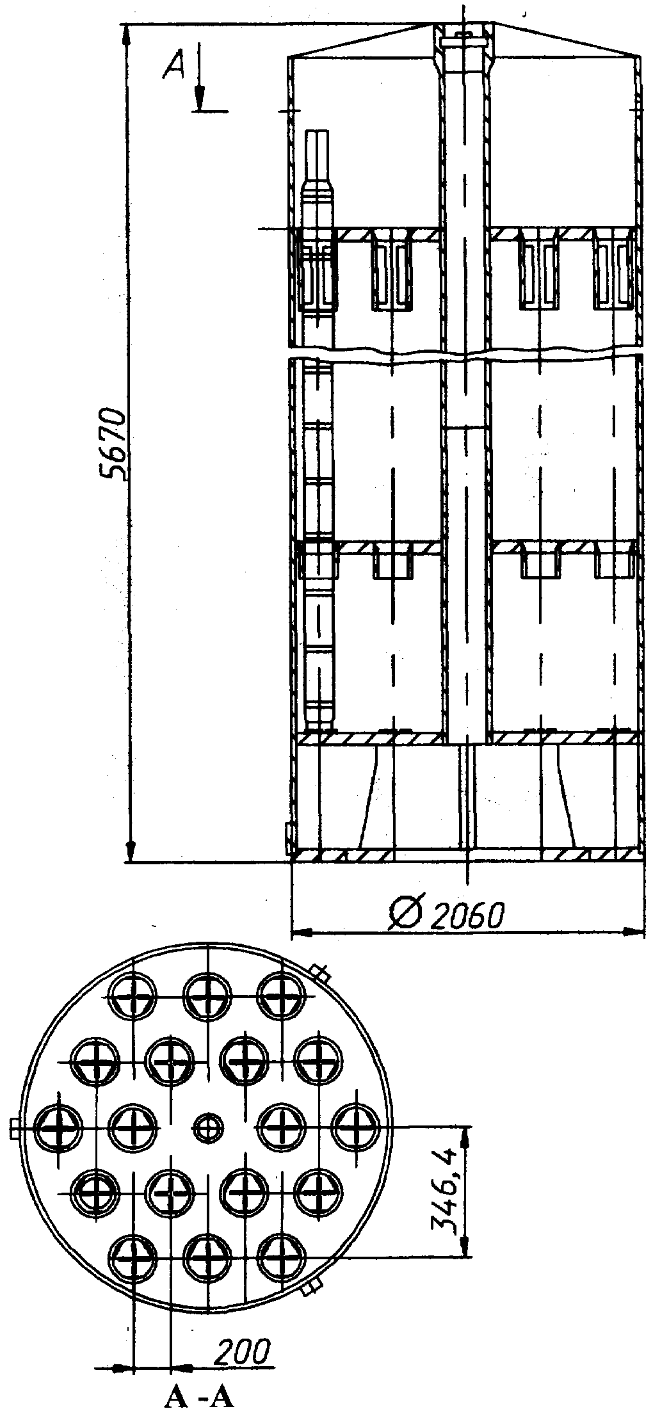
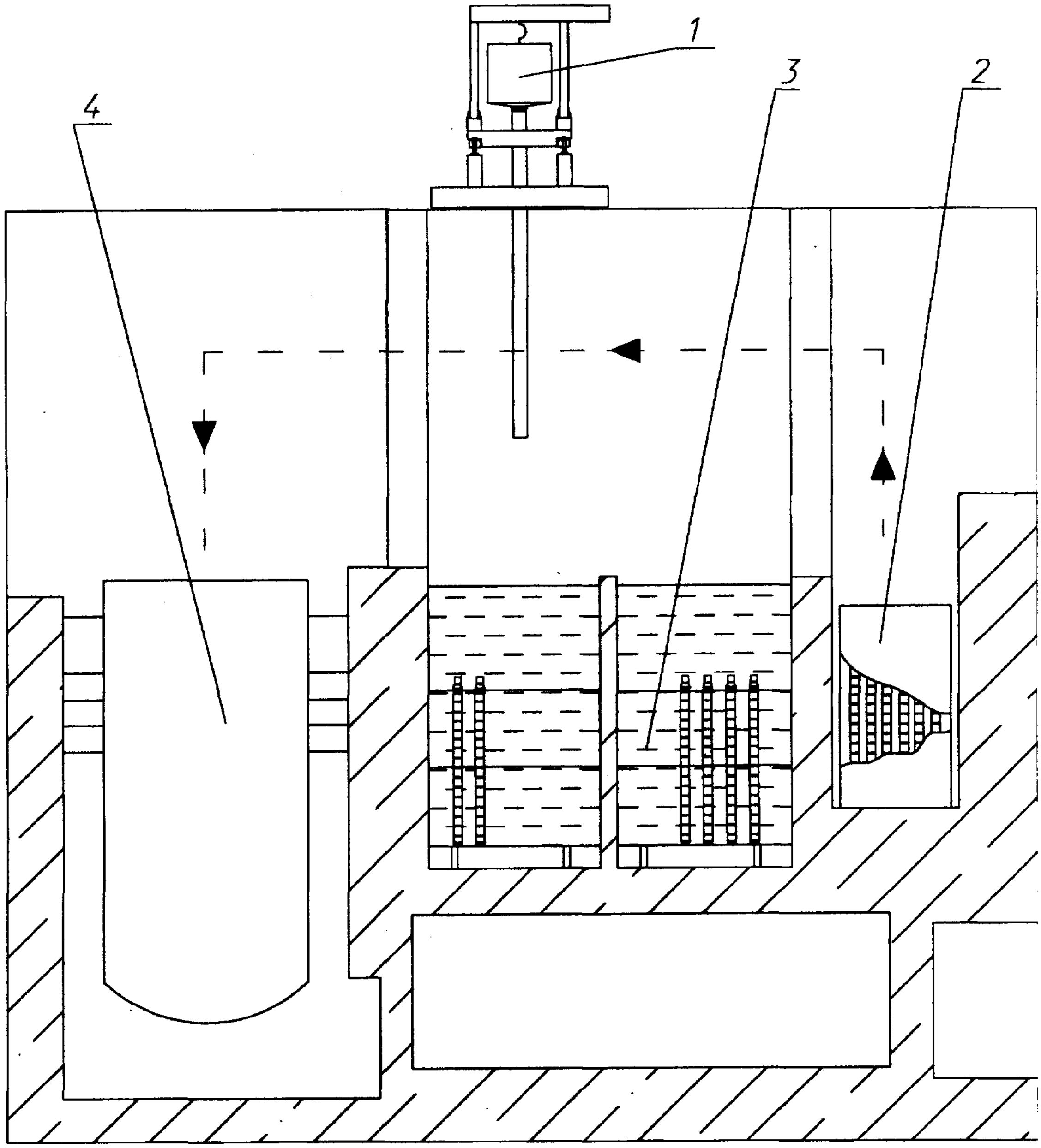


Fig.5 Cover for fresh fuel



1 – Reloading machine
2 - Cover for fresh fuel
3 - Deck of Cooling pool
4 - Reactor

Fig.6 Transportation scheme of fresh FAs from a cover to a reactor

2.2.4 Transport container TK-13

Transport container TK-13 for spent fuel is shown in Fig.7. Scheme of spent FA discharge into container TK-13 is presented in Fig.9. Calculational model of TK-13 is shown in Fig.8. Axial dimension of the calculational model is supposed unlimited.

Two cases are to be considered:

- dry container;
- container filled by water without boron.

These cases characterize conservatively main operational and accidental regimes, because fuel transport is performed in the dry container and loading of the fuel into the container – in the water with boric acid concentration of 16 000 ppm.

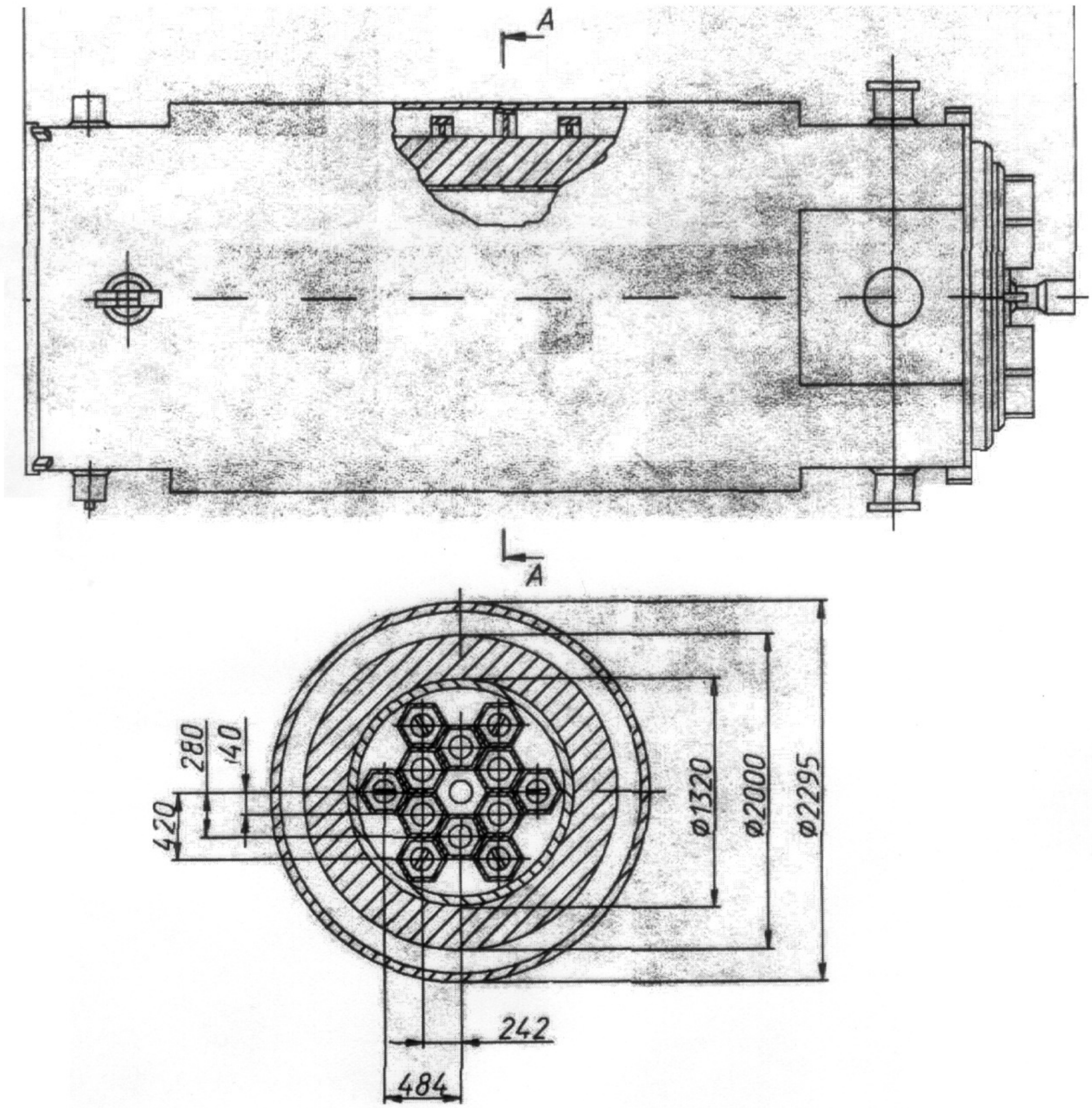


Fig.7 Container TK-13 for spent fuel

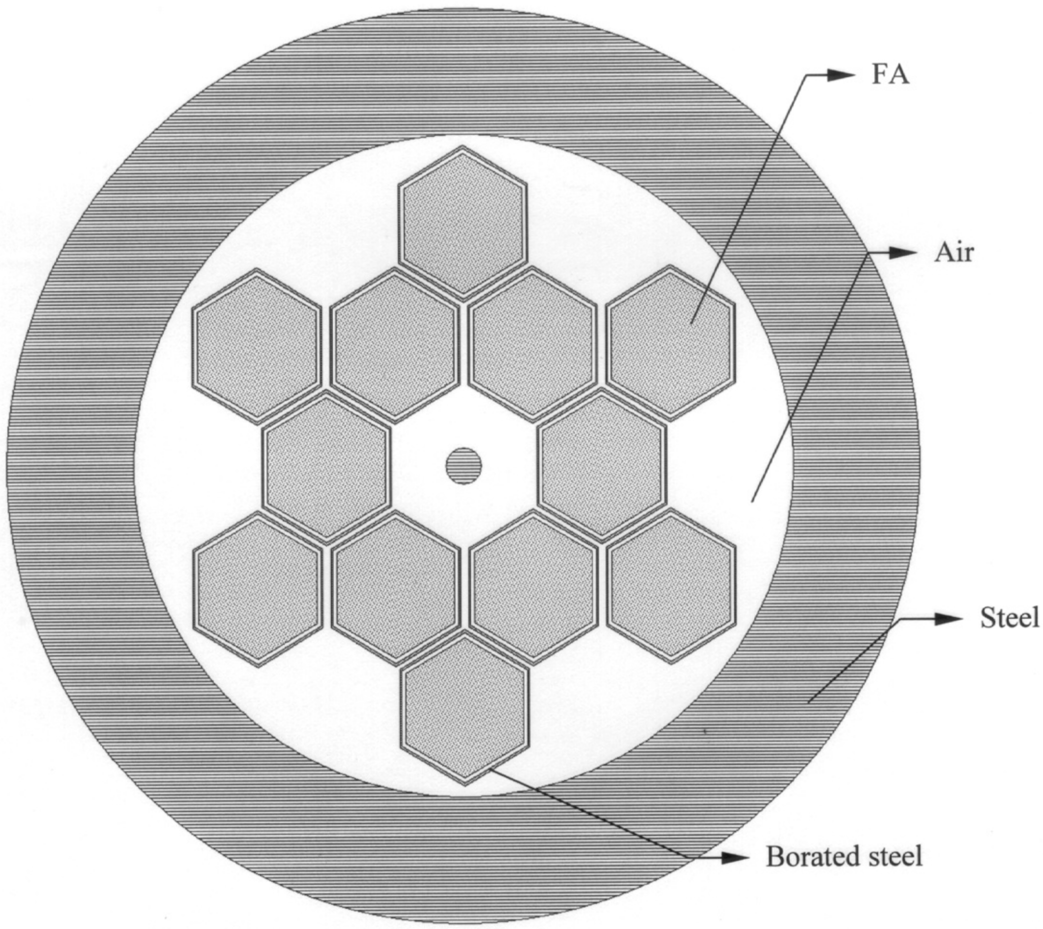
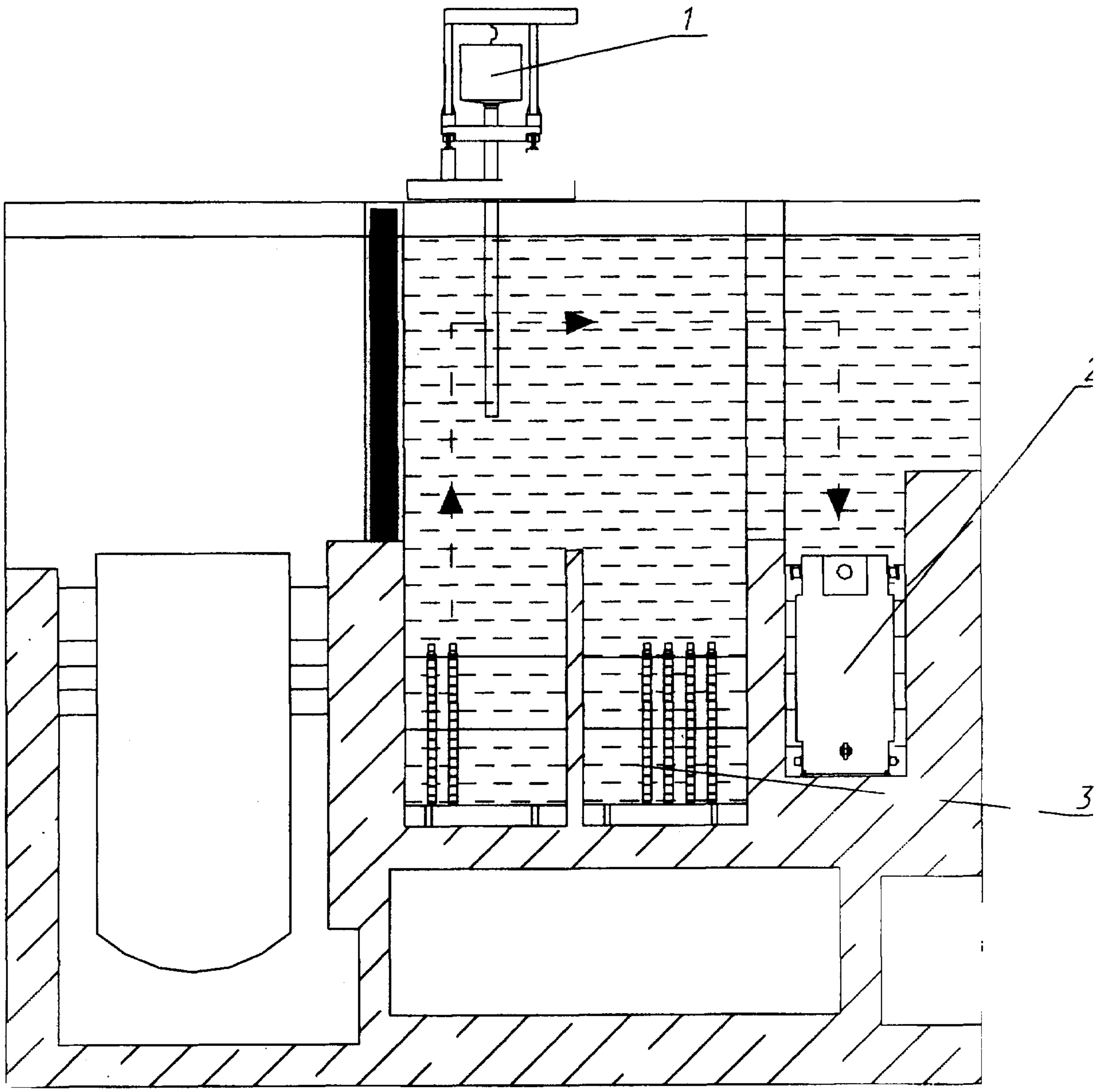


Fig.8 Calculationel model of container TK-13



1- Reloading machine

2 – Container TK-13

3 – Deck of Cooling pool

Fig.9 Scheme of spent FA discharge into container TK-13

3. Radiation Safety

The following tasks concerning dose rates must be resolved :

1.For fresh fuel :

- Unshielded assembly (entry control),
- Package set with 2 assemblies,
- Stacks of 3x5 package sets,
- Cover for fresh fuel with 18 fresh assemblies,
- The same cover with 7 fresh assemblies (it corresposponds to the case of 1/3 MOX core loading),
- Fresh assembly in a boom of reloading machine.

2.For spent fuel :

- Spent assembly in a boom of reloading machine,
- Spent assemblies in container TK-13.

3.1. Initial Data

Two types of fuel are considered: UOX and MOX with weapon-grade plutonium. ^{235}U enrichment in UOX fuel and plutonium content in MOX fuel for all fuel pins in an assembly are taken with a margin that makes correspondingly 4.4 % and 4.2 %. Presence of an integrated burnable poison is refused.

The considered UOX and MOX fuel isotopic composition (%Wt.):

$$^{234}U\ /\ ^{235}U\ /\ ^{238}U = 0.04\ /\ 4.4\ /\ 95.56$$

$$^{238}Pu\ /\ ^{239}Pu\ /\ ^{240}Pu\ /\ ^{241}Pu\ /\ ^{242}Pu = 0.13\ /\ 91.72\ /\ 6.55\ /\ 1.17\ /\ 0.43$$

^{234}U and ^{235}U contents in the wasted uranium of MOX fuel are correspondingly 0.002 % and 0.2 %.

The indicated isotopic compositions of uranium and plutonium correspond to the moment of an enriched uranium fabrication and of plutonium extraction. It is supposed that the period from fuel fabrication until its arrival at a NPP is equal to 2 years. This delay is to be taken into account while estimating of fuel depletion for the nuclides important in dose rates calculations of fresh FAs.

Assembly design parameters are presented in Table 3.1.

Table 3.1. FA characteristics in radiation safety calculations

Characteristic	Value	
	UOX FA	MOX FA
Pitch between assembly and assembly, cm	236	236
"Flat-to-flat" dimension, cm	234	234
Fuel rod number	312	312
Number of Uranium-gadolinium fuel pins	-	-
Pitch between rod and rod, mm	12.75	12.75
Number of guide channels for control rods, items	18	18
Number of space grids, items	15	15
Spacer grid mass, kg	550	550
Material of space grids, guide channels and central tubes	Zr+1%Nb	Zr+1%Nb
Zirconium alloy density, g/cm^3	6.515	6.515
Diameter and thickness of a fuel pin, mm	9.1x0,69	9.1x0,69
Fuel pellet diameter, mm	7.55	7.55
Central hole diameter in a pellet, mm	1.5	1.5
Height of fuel column, mm	3530	3530
Diameter and thickness of a guide tube	13.0x1.0	13.0x1.0
Diameter and thickness of a central tube	13.0x1.0	13.0x1.0
^{235}U enrichment in a fuel, % Wt.	4.400	0.200
Pu content in a fuel, % Wt.	-	4.200
Fuel mass in a fuel pin, kg	1.575	1.575

3.2 Radiation safety in facilities for fuel storage and transport

3.2.1 Unshielded fresh FA

The model of an unshielded FA is shown in Fig.10 in (R, Z) geometry. The model is symmetrical in relation to Z-axis. On all remaining surfaces – vacuum boundary conditions. Zone nuclear concentrations for 2-D (R-Z) calculational model of an unshielded FA is shown in Table 3.2.

Equivalent dose rates are to be estimated on FA surface and at a distance of 10, 50, 100 and 200 cm from it. The following radiation components influencing a dose value are to be taken into account: source neutrons, generation neutrons, capture gamma-radiation, actinide gamma-radiation and braking (X) radiation.

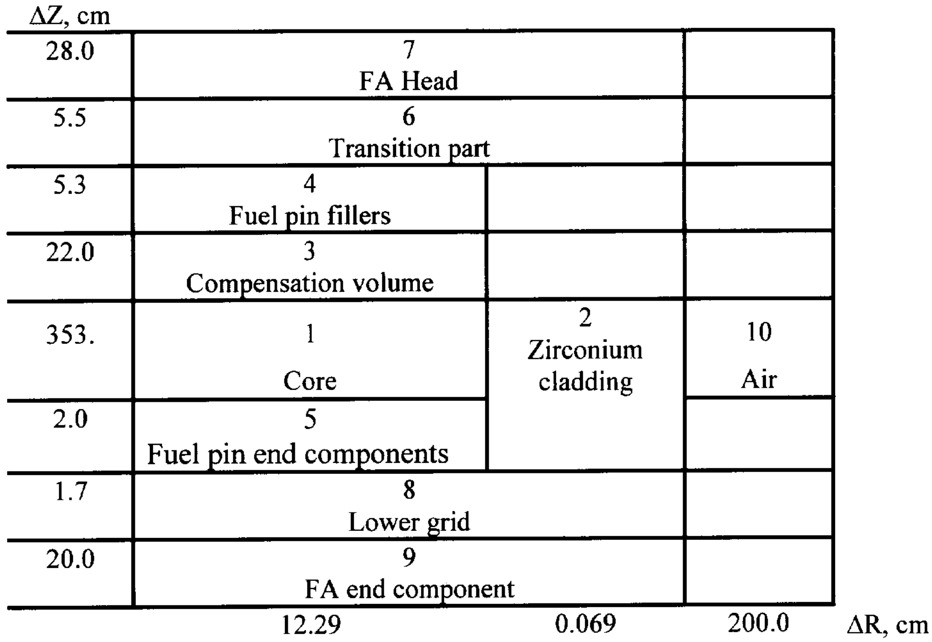


Fig.10 (R,Z) calculational model of unshielded FA

Table 3.2. Zone nuclear concentrations for 2-D (R-Z) calculational model of an unshielded FA (10^{24} 1/см^3) *)

№ Zone / Element	1 UO$_2$	1 MOX	2	3	4	5	6	7	8	9	10
C	-	-	-	5.682E-6	2.304E-5	2.210E-5	-	5.682E-5	1.042E-4	1.042E-4	-
N	-	-	-	-	-	-	-	-	-	-	3.916E-5
O	1.309E-2	1.309E-2	-	-	-	-	-	-	-	-	1.107E-5
Ti	-	-	-	1.781E-5	7.223E-5	6.926E-5	-	1.781E-4	3.265E-4	3.265E-4	-
Cr	-	-	-	3.035E-4	1.231E-3	1.180E-3	-	3.034E-3	5.563E-3	5.563E-3	-
Fe	-	-	-	1.068E-2	4.332E-3	4.153E-3	-	1.068E-2	1.958E-2	1.959E-2	-
Ni	-	-	-	1.526E-4	6.188E-4	5.933E-4	-	1.526E-3	2.797E-3	2.797E-3	-
Zr	5.568E-3	5.568E-3	4.258E-2	5.568E-3	1.303E-2	1.490E-2	6.408E-4	-	4.258E-3	-	-
Nb	5.522E-5	5.522E-5	4.223E-4	5.522E-5	1.293E-4	1.478E-4	6.355E-6	-	4.223E-5	-	-
U-234	2.662E-6	6.655E-8	-	-	-	-	-	-	-	-	-
U-235	2.916E-4	1.259E-5	-	-	-	-	-	-	-	-	-
U-238	6.256E-3	6.256E-3	-	-	-	-	-	-	-	-	-
Pu-238	-	3.572E-7	-	-	-	-	-	-	-	-	-
Pu-239	-	2.510E-4	-	-	-	-	-	-	-	-	-
Pu-240	-	1.784E-5	-	-	-	-	-	-	-	-	-
Pu-241	-	3.176E-6	-	-	-	-	-	-	-	-	-
Pu-242	-	1.162E-6	-	-	-	-	-	-	-	-	-

*) Indicated uranium and plutonium isotopic nuclear concentrations correspond to the moment of an enriched uranium fabrication and of plutonium extraction. To be used in calculations the actinide compositions in UOX and MOX fuel are to be corrected taking into account nuclear decay products important for a dose rate from a fresh FA. It is supposed that the period from fuel fabrication until its arrival at a NPP is equal to 2 years

3.2.2 FA storage in package sets for fresh fuel

Calculational model for one tube with FA corresponding to package set design is shown in Fig.11. The composition is symmetrical in relation to Z-axis. Nuclear compositions in the zones 1-10 are identical to those indicated in Table 3.2 (comments included). Compositions in the zones 11 and 12 are presented in Table 3.3.

Table 3.3. Nuclear concentrations of zones № 11 and № 12 of 2-D (R-Z) calculational model of FA in a package set (10^{24} 1/см^3)

№ zone Element	10	11
H	1.882E-2	-
C	1.242E-2	8.068E-4
O	8.299E-3	-
Si	-	4.544E-4
Cr	-	2.273E-4
Mn	-	4.302E-4
Fe	-	8.363E-2

Equivalent dose rates are to be estimated on FA surface and at the varying distance from it.

Then the obtained dose rate distributions using superposition method are to be obtained in a direction perpendicular to the line connecting FA axes for two cases, shown in Fig. 12: I - in the plane passing through the centre between FAs (R=0 corresponds to a level of tangent to container tube surfaces) and II – in the plane passing through an axis of one of container tubes.

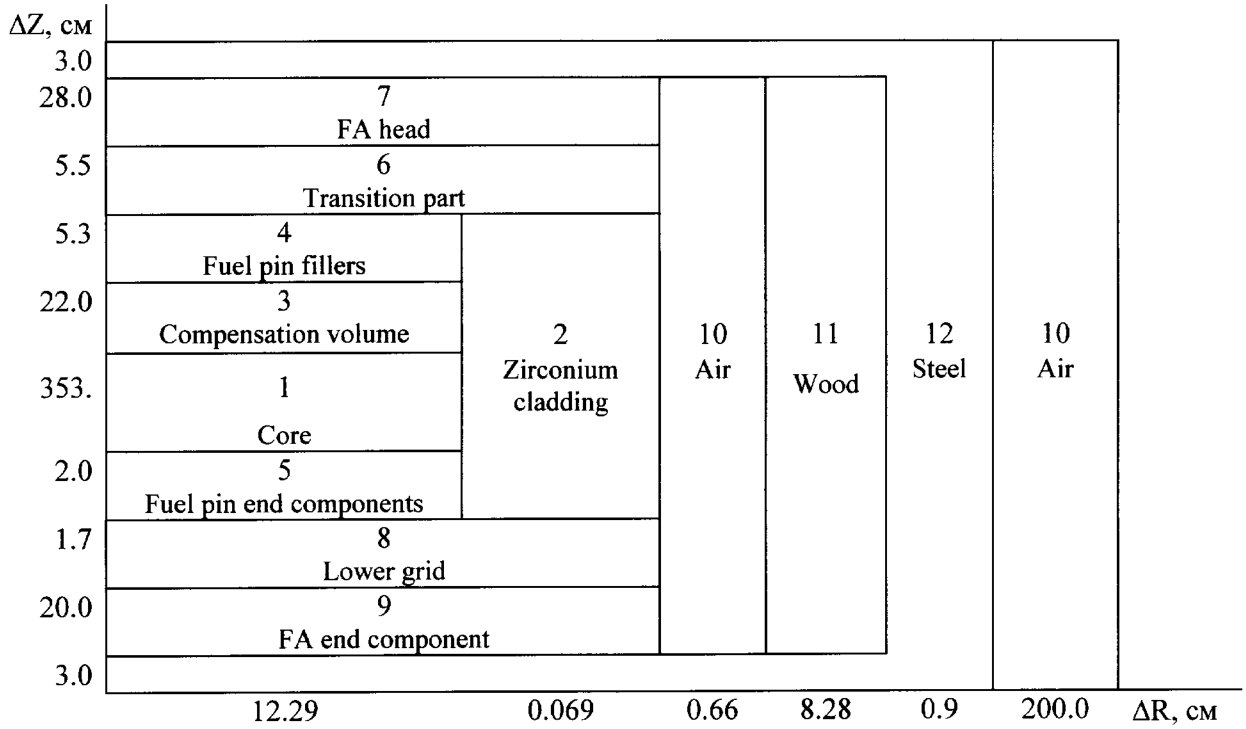


Fig. 11 Calculation (R, Z)-model of one FA in a package set

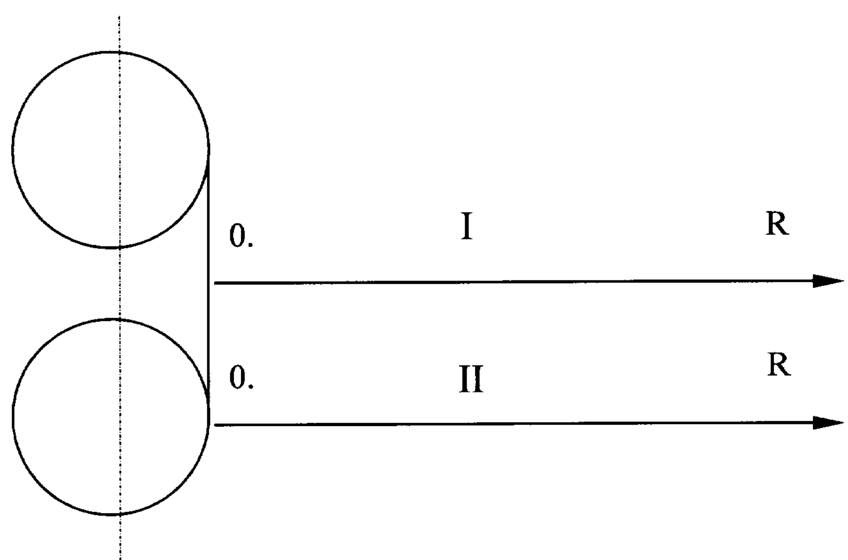


Fig.12 Location of axes of dose rate radial distribution from two FAs in a package set

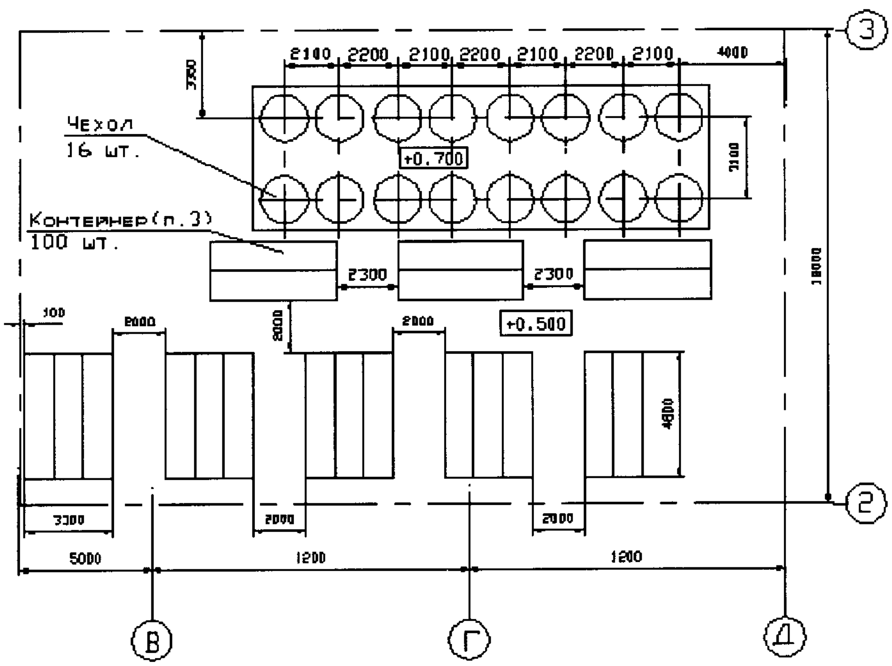
3.2.3 Stacks of package sets

MOX fuel storage can be performed in stacks of package sets. A stack consists of 5 triers with 3 package sets in everyone. Passage between stacks equals to 2m. The location of package sets in a fresh fuel depository is shown in Fig.13.

It is required to calculate equivalent dose rates:

- in the middle of the passage from the nearest FA,
- in the middle of the passage from all FAs,
- at the boundary of passage from all FAs (from the left and right).

Dose rates of neutrons and of gamma-radiation while fresh fuel stocking is to be calculated by the source superposition method (separate FAs) using the dependencies obtained in p.3.2.2.



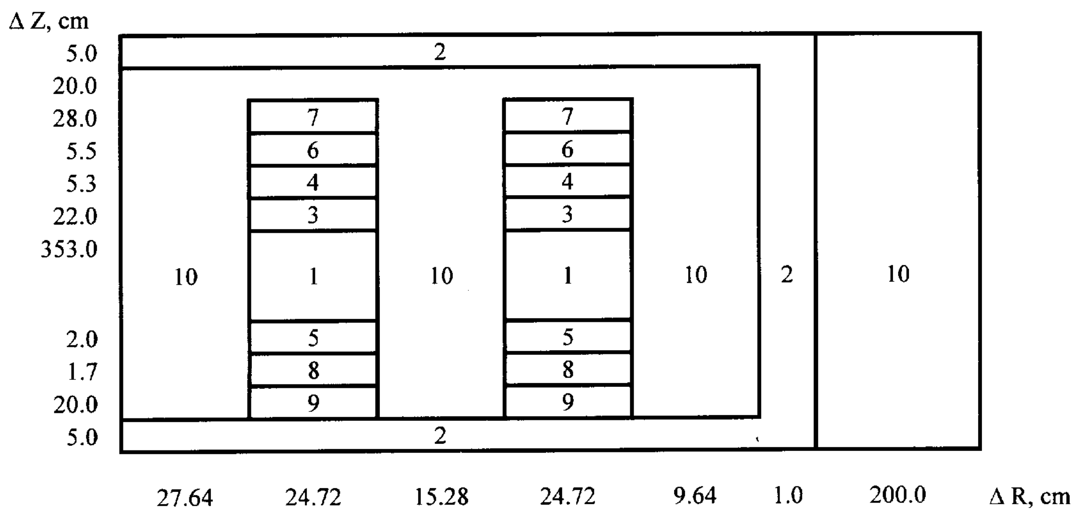
Примечания
1. Вместимость чехла - 18 ТВС
2. Вместимость контейнера - 2 ТВС
3. Количество ярусов контейнеров в штабеле - 5

Fig. 13. Location of covers and containers with fresh FAs in Fresh Fuel Depository

3.2.4 Covers for Fresh FAs

Calculational model for a cover in two-dimensional (R, Z)-geometry is shown in Fig.14.

FA location in a cover is modelled by two layers, in which 6 and 12 FAs (full cover loading) are mixed homogeneously. The distances to be calculated are: 0, 10, 50, 100 and 200 cm.



Notations:

1 - Core
2 - Jacket steel
3 - Compensation volume
4 - Fuel pin fillers
5 - Fuel pin end
6 - Transition part
7 - FA head
8 - Lower grid
9 - FA end component
10 - Air

Fig. 14 Calculation (R,Z)-model of a cover for fresh FA

Zone nuclear concentrations of the calculational 2-D (R-Z) model of a cover for fresh FAs are presented in Table 3.4.

Table 3.4. Zone nuclear concentrations for 2-D (R-Z) calculational model of a cover for fresh FAs (10^{24} 1/см^3)

№ zone	1		2	3	4	5	6	7	8	9	10
Element	UO_2	MOX									
C	-	-	3.160E-4	2.604E-6	1.056E-5	1.013E-5	-	2.604E-5	4.776E-5	4.776E-5	-
N	-	-	-	-	-	-	-	-	-	-	3.916E-5
O	5.999E-3	5.999E-3	-	-	-	-	-	-	-	-	1.107E-5
Ti	-	-	9.896E-4	8.163E-6	3.311E-5	3.174E-5	-	8.163E-5	1.496E-4	1.496E-4	-
Cr	-	-	1.686E-2	1.391E-4	5.642E-4	5.408E-4	2.913E-6	1.391E-3	2.550E-3	2.550E-3	-
Fe	-	-	5.935E-2	4.895E-3	1.986E-3	1.903E-3	2.937E-4	4.895E-3	8.974E-3	8.974E-3	-
Ni	-	-	8.477E-3	6.994E-5	2.836E-4	2.720E-4	-	6.994E-4	1.282E-3	1.282E-3	-
Zr	2.772E-3	2.772E-3		2.549E-3	5.972E-3	6.829E-3	-	-	1.952E-3	-	-
Nb	2.764E-5	2.764E-5		2.531E-5	5.926E-5	6.774E-5	-	-	1.936E-5	-	-
Actinides	*)	*)	-	-	-	-	-	-	-	-	

*) Actinide nuclear concentrations correspond to those in Table 3.2 (comments included) multiplied by the factor 0.458 (it takes into account a homogenization in the interior of annular zones).

3.2.5 Fresh FA Reloading

Reloading is carried out by a reloading machine, which grips FA with the help of a boom. The boom includes two coaxially located tubes ∅30×0.9 and ∅41×1.5 cm. The reloading can be either "dry" or under water layer.

Fig. 15 presents the corresponding calculation (R,Z)-model of FA in reloading machine boom. Notations 1-10 in Fig. 15 are analogous to the notations in Fig. 10. Material 11 models water, and 12 - boom tube steel. The composition is symmetric about the Z-axis.

It is required to determine equivalent dose rate values at the level of reactor room floor, at the distance of 0.5 m and 1.0 m from it and at the level of reloading machine bridge (~2 m from the floor). In the case of FA transportation under water layer (2.5 m of water above FA head), it is needed to determine a dose rate at the water surface level.

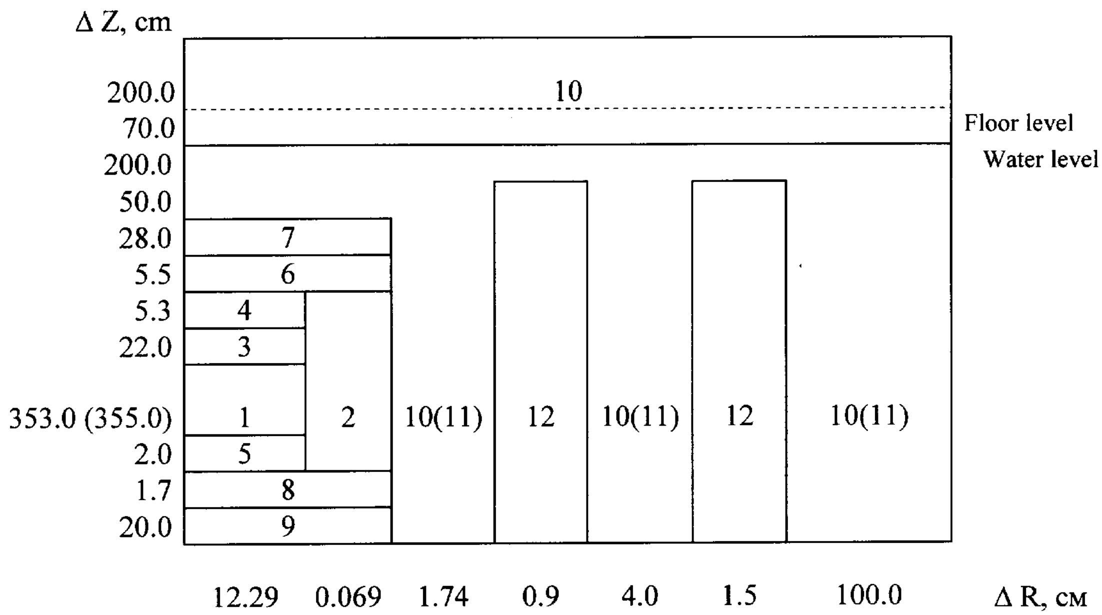


Fig.15 Calculation (R,Z)-model for FA in reloading machine boom

Composition of zones 1-10 is identical to Table 3.2. Composition of zones 11 and 12 is identical to Table 3.5.

Table 3.5. Nuclear concentrations of zones № 11 and № 12 of 2-D (R-Z) calculational model of FA in reloading machine boom (10^{24} 1/cм^3)

№ zone / Element	11	12
H	0.06686	-
C	-	3.160E-4
O	0.03343	-
Ti	-	9.896E-4
Cr	-	1.686E-2
Fe	-	5.935E-2
Ni	-	8.477E-3

3.2.6 Spent fuel

The following burnup levels are considered to determine isotopic composition and radiation sources for a spent fuel:

- UOX fuel: 47.0 MWd/kg HM;
- MOX fuel: 40.0 MWd/kg HM.

Burnup is calculated for a constant power 18.4 MW generated in FA in an infinite grid of FAs.

It makes an effective irradiation length:

For UOX fuel – 1106 EFPD;

For MOX fuel – 942 EFPD.

^{10}B and ^{11}B concentrations in water rest constant. Critical state in a system at every time step is ofensured by a choice of buckling (B^2) value. Nuclear concentrations and temperatures of fuel, claddings and moderator are presented in Table 3.6. FA geometrical characteristics are presented in Table 3.1. The calculation of nuclide concentrations is performed under the following approach:

- Fuel is homogenized inside the cladding;
- Fuel column height in an operating state is 355 cm;
- ^{241}Pu decay during 2 years and ^{241}Am generation until FA loading in a reactor is considered.

Transportation operations with spent fuel begin in approximately 3 days after reactor shutdown for reloading. Next important stage of spent fuel treatment begins in approximately 3 years when transport containers with spent fuel, withdrawn from cooling pool, are to be transported to fuel treatment plants.

Table 3.6. Nuclear concentrations (10^{24} 1/cm^3) and temperatures in model zones for burnup calculations

Material	***Fuel***		***Cladding***	***Moderator***
T, K	1027		575	575
Fuel material	***UOX(4.4 %)***	***MOX(4.2 %)***		
H	-	-	-	4.783E-2
^{10}B	-	-	-	4.7344E-6
^{11}B	-	-	-	1.9177E-5
^{16}O	4.230E-2	4.227E-2	-	2.391E-2
Zr	-	-	4.257E-2	-
Nb	-	-	4.222E-4	-
Hf	-	-	6.593E-6	-
^{234}U	8.6E-6	2.1E-7	-	-
^{235}U	9.420E-4	4.102E-5	-	-
^{238}U	2.020E-2	2.021E-2	-	-
^{238}Pu	-	1.154E-6	-	-
^{239}Pu	-	8.110E-4	-	-
^{240}Pu	-	5.767E-5	-	-
^{241}Pu	-	9.294E-6	-	-
^{242}Pu	-	3.755E-6	-	-
^{241}Am	-	9.64E-7	-	-

3.2.7 Spent FA Reloading

For 2-D calculations of spatial distribution of equivalent dose rates while FA reloading the same calculational model as for fresh fuel FA (Fig.15) is to be used.

Nuclear concentrations of zone 1 correspond to the nuclear concentrations of the fuel zone in Table 3.6 after irradiation and delay of 3 days multiplying by the factor 0.308 (fuel fraction in zone 1). Homogenized source values in zone 1 after delay of 3 days are calculated in the same manner.

Reloading is performed under water.

It is required to determine equivalent dose rate values at the level of reactor room floor (Z=70 cm) and at the distance of 0.5 m, 1.0 m and 2.0 m (level of reloading machine bridge).

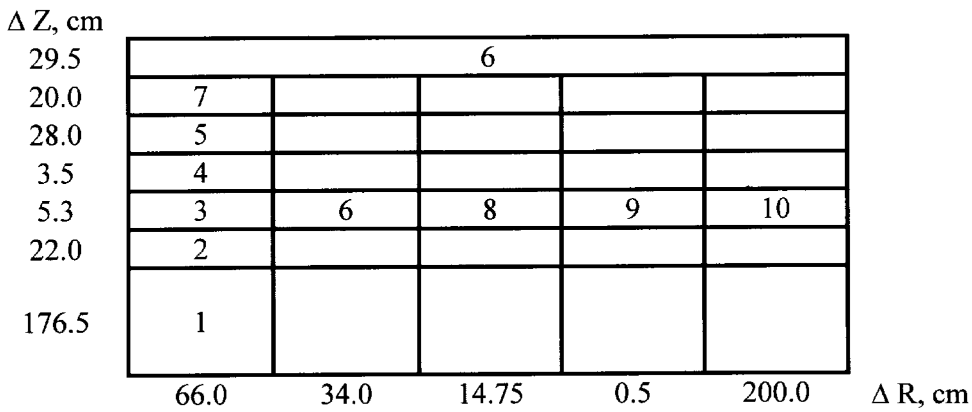
3.2.8 Container TK-13 for spent fuel

2-D model for container calculation is presented in Fig.16. The model is symmetrical in relation to R and Z axes.

Equivalent dose rates are to be calculated on container top and at the distance 0, 10, 50, 100 and 200 cm from container surface.

Nuclear composition and zone temperatures of the calculational model are presented in Table 3.7.

FAs are homogenized in the interior of cover. Nuclear concentrations of zone 1 correspond to the nuclear concentrations of the fuel zone in Table 3.6 after irradiation and delay of 3 days multiplying by the factor 0.128 (fuel fraction in a cover for 12 FAs location). Homogenized source values are calculated in the same manner.



1 – core

2 – compensation volume

3 – pin fillers

4 – transient part

5 - pin head

6 – cover, container top and neutron shielding

7 – air

8 – antifreeze "65"

9 – container jacket.

Fig.16 Calculational model of container TK-13

Table 3.7. Nuclear concentrations (10^{24} 1/cм^3) and zone temperatures of 2-D (R-Z) calculational model for a container TK-13

№ zone	**1**		**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Fuel	**UO_2**	**MOX**									
T, K	**523**	**523**	**523**	**523**	**523**	**523**	**300**	**523**	**300**	**300**	**300**
H	-	-	-	-	-	-	-		6.554E-2	-	-
$B_{nat.}$	2.605E-4	2.605E-4	2.605E-4	2.605E-4	2.605E-4	2.605E-4	-	-	-	-	-
C	-	-	2.365E-6	9.593E-6	-	2.365E-5	3.160E-4	-	1.405E-2	2.370E-4	-
N	-	-	-	-	-	-	-	2.194E-5	-	-	3.916E-5
O	5.414E-3	5.411E-3	-	-	-	-	-	6.200E-6	2.575E-2	-	1.107E-5
Ti	-	-	7.405E-6	3.004E-5	-	7.405E-5	9.896E-4	-	-	-	-
Cr	7.712E-4	7.712E-4	8.974E-4	1.283E-3	7.712E-4	2.033E-3	1.686E-2	-	-	-	-
Fe	2.706E-3	2.706E-3	7.147E-3	4.507E-3	2.706E-3	7.147E-3	5.935E-2	-	-	8.311E-2	-
Ni	3.878E-4	3.878E-4	4.513E-4	6.451E-4	3.878E-4	1.022E-3	8.477E-3	-	-	1.614E-3	-
Zr	2.516E-3	2.516E-3	2.516E-3	5.418E-3	2.673E-4	-	-	-	-	-	-
Nb	2.495E-5	2.495E-5	2.495E-5	5.376E-5	2.649E-6	-	-	-	-	-	-
Actinides, Fission products	*)	*)	-	-	-	-	-	-	-	-	-

*) Nuclide concentrations (except of oxygen) of zone 1 in Table 3.6 after irradiation and 3-year delay multiplied by the factor 0.128.

References

1. Poruchikov V.A. "Transport-Technological operation with the Nuclear Fuel at Balakovo NPP". Balakovo NPP, 2000.
2. Safety rules for nuclear fuel storage and transport at the nuclear engineering object. PNAEG-14-029-91, Moscow, Energoatomizdat, 1992.
3. Pavlovichev A.M. MISSION MOX FUEL PHYSICS DESIGN. Preliminary Equilibrium MOX Assembly Design and Expected Operating Power for Existing Balakovo Fuel Management Scheme. RRC KI. Moscow, 2000.

Comments from S. Goluoglu and R. T. Primm III, ORNL, on *Description of Fresh and Spent Fuel Storage at Balakovo NPP—Definitions for Safety Calculations*

GENERAL NOTES

1. Dimensions and material types for the containers and assemblies are not complete. Examples follow:
    a. dimensions and materials of the tubes that comprise the tyks;
    b. pin dimensions;
    c. fresh fuel assembly dimensions and materials and central support structure material and dimensions;
    d. density of MOX and UO_2;
    e. details of U-Gd rods such as weight percents and isotopic compositions.
2. The word “cover” is used to imply “container.”
3. Previously the Balakovo Plant indicated that only 16 of 18 positions in the fuel transportation vehicle (FTV) were occupied. Section 7.2.3 indicates that all positions are filled. ORNL had shown that fully loaded FTV results in a k_{eff} of greater than 0.95 if it is flooded with low-density water. Has the Balakovo Plant changed the practice of 16 assemblies per FTV? How do they justify going over 0.95? Is low density water not a credible condition?
4. It looks as though the FTV is not 30 cm thick (contrary to an earlier document). TK-13, which is only used for spent fuel, is 30 cm thick.
5. How are the tyks stacked on the railroad car and at the reactor site? How many are in a row? How many tiers? More than one row?
6. The word “supposed” is used to imply “assumed.”
7. Units should be small letters not small caps (e.g., cm not CM).
8. If American English is desired, the commas in values should be periods.

SPECIFIC COMMENTS

1. Page 6, second paragraph: The definition of “decks” is unclear but is apparently (according to paragraph 4) a tray of some sort that is part of the cooling pool.
2. Page 6, third paragraph, comment: In previous reports and presentations, the United States had referred to a “within plant fresh fuel transport vehicle.” Apparently the correct term is “cover for fresh fuel.”
3. Page 6, paragraph 4, second to last line: The word “exposition” should be “exposure.” Sentence needs to be corrected.
4. Page 7, bulleted list, item 2: Delete “one” after ^{240}Pu.
5. Page 7, bulleted list, item 3: Replace “additional increase of ” with “increasing.”
6. Page 9, Table 2.2: Rod dimensions have a nonstandard format. We suggest adding new rows with rod thicknesses. Also, replace commas in values with periods.
7. Page 9, Table 2.2: “Contents in the fuel” is not clear. Is it weight percent in the oxide, or weight percent of uranium, or uranium and plutonium in the case of MOX?

8. Page 9, Table 2.2: Pellet dimensions are needed.
9. Page 10, Section 2.2.1, line 1: Replace “His” with “A”; replace “given” with “shown”; and remove “the” before “Fig. 3.”
10. Page 10, Section 2.2.1, line 2: reword: Cell dimensions in x and y directions are 620 mm and 550 mm, respectively.
11. Page 14, Section 2.2.2, paragraph 1, line 1: Change “closed” to “close-packed.”
12. Page 14, Section 2.2.2, paragraph 1, line 3: Complete the title of Ref. 2.
13. Page 14, Section 2.2.2, paragraph 1, line 5: Change sentence to “Assemblies are assumed to be infinite axially, except where indicated in the text.”
14. Page 14, Section 2.2.2, paragraph 2, last sentence: Split in two sentences at comma. Change “boron acid” to “boric acid” and “current” to “water” or “coolant.”
15. Page 19, comment: Less-than-full-water-density-but-non-zero cases have been excluded. It is unlikely that the humidity inside the plant is zero, and an increase in water density from zero up to approximately 0.2 g/cm^3 is a positive reactivity effect.
16. Page 19, last line: Y. Styrine, RRC-KI, confirmed that the boric acid concentration of 16,000 ppm is correct and corresponds to the concentration of boric acid in a cooling pond that is always constant.
17. Table 2.3: Tube material should be borated steel.
18. Page 24, Section 3.1, paragraph 1: Clarify first paragraph. Are these weight percents of fresh fuel? If so, why are they different from Table 2.1 values?
19. Page 24, paragraph that starts with ^{234}U: Remove “wasted” from “wasted spent.”
20. Page 25, Table 3.1: Add thicknesses as new rows, change commas to periods, and add more information as in Table 2.2.
21. Page 29, paragraph 1: Paragraph and table title refer to zones 11 and 12. Table itself shows zones 10 and 11.
22. Page 31, paragraph 1, line 2: The term “triers” should be “tiers,” “everyone” should be “each tier,” and “passage” should be “distance” or “wall-to-wall distance.”
23. Page 32, paragraph 2: Confusing; please clarify.
24. Page 36, paragraph 3, line 2: The term “ofensured” should be “ensured.”
25. Page 37, paragraph 1, line 2: Remove “fuel” in “… for fresh fuel FA.”
26. Page 37, paragraph 2, line 2: The word “multiplying” should be “multiplied.”
27. Page 38, paragraph 4: What does interior of cover mean? Is it inside surface of the top lid (cover)?
28. Page 38, paragraph 4, line 3: The word “multiplying” should be “multiplied.”
29. Page 38, paragraph 4, line 3: It refers to fuel fraction in a cover. Is cover the container?
30. Fig. 6, comment: It would seem that a safety-related scenario that should be examined is the inadvertent drop of an assembly into the storage pool.
31. Fig. 9: See comment for Fig. 6.
32. Fig. 10: The two “boxes” above zone 2 (zirconium cladding) are also assumed to be zone 2. The “boxes” above and below zone 10 are also assumed to be air.

33. Fig. 13: Russian text needs to be translated to English.
34. Fig 16: Add “10 – air.”
35. Page 36, third paragraph: The word “ofensured” is assumed to be a typographical error and should be “ensured.”

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