Annex B. Description of alternative types of a reactor facility for construction of KNPP-3,4 and substantiation of the benefits of the chosen type

1 Procedure to select the reactor facility for construction of KNPP-3,4

The choice of the Reactor Facility (RF) for construction of power units KNPP-3,4 was held prior to FS elaboration and comprised 2 stages:

- Tentative analysis of possible alternatives;
- Selection of the RF suppliers through international tenders.

The following potential suppliers of the reactor facilities VVER/PRW were invited to participate in the tender:

- OKB “Hydropress” (Russia);
- SKODA JS (Check Republic);
- AREVA (France-Germany);
- Westinghouse (USA);
- KEPCO (Republic of Korea).

Criteria for bids preparation (elaborated by Energoatom and approved at the session of the division “Nuclear Energy” of the Scientific and Technical Council of the Ministry of Fuel and Energy Industry on 10.04.2008) were sent to them.

Only three companies - designers, which offered the RF of the exclusively water pressurized type, participated in the international tenders. The agreement to participate in the tenders and bids from OKB “Hydropress” (ZAO “Atomstroyeksport”), KEPKO and Westinghouse were received.

During the tenders, Westinghouse refused from the further participation in the tenders. Thus, the bids of two participants: ZAO “Atomstroyeksport” (Russia) – design VVER-1000/B-392B and KEPKO (Korea) – design APR-1400, were evaluated.

In line with the conclusions of the tender committee, of the recommendations of the Scientific and Technical Council of the Ministry of Fuel and Energy Industry Board (“Approval of the decision on the choice of the RF for construction of the power units 3 and 4 of Khmelnytska NPP” №4.1 of 13.10.2008), the reactor facility B-392 was chosen as the RF for new power units. Since the tentative analysis covered a wider range of possible alternatives, including the RF, designed according to the considerably different nuclear technologies, the results of this very comparative analysis is given below.

2 Possible variants of the power unit type for KNPP-3,4 completion

Power units with the reactors on thermal neutrons are the basis of the international nuclear energy. When choosing the alternative variants of the power units type for KNPP-3,4, initially it was accepted to focus on light-water reactors of the VVER type, PWR types (pressurized water reactors) and reactors CANDU (heavy-water reactors), BWR (boiling water reactors), fast fission reactors (BN) and gas-cooled reactors (VTGR) were not considered as possible alternatives, taking into account that Ukrainian nuclear energy sector has more than 300 reactor/years of experience in the operation of power units with light-water reactors.

Experience of the international nuclear energy sector and experience of construction and operation of reactors in Ukraine enable to give preference to pressurized water power units (PWR/VVER). The choice of this power unit was substantiated during preparation of the “National Energy Program of Ukraine up to 2010” and determined by the Energy Strategy of Ukraine up to 2030 (Section 4, Par.4.1).

For the analysis of possible variants of RF VVER/PWR types for completion of KNPP-3,4, the power units which already have the operating experience, or evolutionary designs with the high degree of readiness to be implemented: the series of VVER designs; PWR - AP-1000, EPR-1600 designs, System 80+, APR-1400 were chosen.

Each of the listed designs is mainly in compliance with the IAEA regulations, requirements of European companies - NPP operators; they have passed the inspections for compliance with the national standards in nuclear and radiation safety (licensed by the regulatory body of the country of origin) and can be licensed in Ukraine.

According to the degree of compliance with the established criteria of the selection, the evolutionary power unit designs VVER-1000, power units PWR AP1000 with the capacity 1150 MW of the company “Westinghouse”, APR-1400 of the Korean reactors of new generation and EPR-1600 (European Power Reactor) with the capacity 1550 MW of the firm AREVA were determined as the alternative variants.

3 Summary of the selected designs

AP-1000

Basic advantages of the AP1000 Westinghouse technologies are as follows:

- Relative simplicity of the RF design;
- Implementation of passive safety systems, which are much simpler, more reliable and less expensive (no pumps, ventilators as well as diesel-generators and other alternating-current generators are used) than the active systems, performing the same functions. As the result, in the design AP1000 the number of systems and equipment elements is reduced by 50%.

Disadvantages of the AP1000 design are as follows:

- “revolutionary character” of the technical safety systems, lack of additional practical confirmations;
- Lack of reference of applied solutions, especially regarding safety systems;
- Partial compliance with the requirements of effective regulatory documents in Ukraine will result in the complication of the procedures to review and get the approval of the design, in certification and licensing of the service life cycle.

EPR-1600

Design EPR-1600 is the model, developed based on French N4 and German KONVOI, operating in France and Germany.

EPR-1600 is not innovative from the point of view of design decisions and the wide, as in AP1000, application of passive safety systems. Safety system elements with the passive principle of operation are used in it, as well as in the evolutionary VVER-1000.

Evolutionary design EPR-1600 is based on the big experience of the PWR reactors operation, foremost on the latest previous technologies: reactors N4 and KONVOI. EPR-1600 has the significantly improved level of safety, especially in the mitigation of severe accidents through restriction of their consequences by the boundaries of the power units itself, which can be achieved through double containment, resistant to the outside impacts, including a crash of a military or of a big commercial airplane and an earthquake.

The disadvantage of the EPR-1600 use for KNPP-3,4 is that the resource of the water consumption of KNPP site is not reckoned for the NPP capacity increase up to 5100 MW through two EPR-1600 power units with the capacity 1550 MW each.

General disadvantages of the AP1000 and EPR-1600 use for KNPP-3,4:

- Impossibility to use and necessity to dismantle a construction part of the power units 3,4, infrastructure and equipment;
- There are no constructed and commissioned power units, which means that there is no experience in operation, repair and maintenance of similar facilities, which can call into question the power units commissioning before 2016;
- Involvement of Ukrainian enterprises in all spheres related to the construction, repair, maintenance and operation, will be restricted;
- Difficulties in preparation of the operational and maintenance personnel, necessity to involve a big number of staff from foreign companies in all spheres, documentation and communication in English;
- Servicing of a new fuel cycle, including the use of a separate procedure of fuel management of new power units;

• Impossibility of the railway transportation of the most overall equipment, high price for transportation (from 600 to 950 million UAH per unit) and adaptation of roads, necessity to complete the equipment at the NPP site practically eliminate the chance to apply AP1000 and EPR-1600 for completion of KNPP-3,4.

VVER-1000

More than 300 reactor/years of the experience of power units operation with VVER-1000 reactors in Ukraine and more than 180 reactor/years of operation in Russia, Check Republic and Bulgaria enable to give a precise description of the peculiarities of the evolutionary VVER-1000. The analysis didn’t show significant discrepancies of the VVER-1000 usage at KNPP site in line with the criteria of the pre-selection.

Advantages of usage of the design during KNPP-3,4 construction are as follows:

• Compliance with the requirements of the effective regulatory documents in Ukraine;

• Possibility to use the completed construction part of the power units 3 and 4 and of the existing infrastructure (17-19% of the full cost estimate of the VVER-1000 power units cost has been drawn), usage of the supplied equipment;

• Supply of the biggest part of the equipment can be ensured by Ukrainian suppliers for the operating NPPs (part of the RF equipment, turbo-installation, monitoring and control systems, electrical equipment, accessories).

Advantages of the uniformity of power units at the KNPP site:

• Usage of the standard VVER fuel and tried and tested procedure of fresh and spent nuclear fuel management;

• Usage of the experience in operation of similar facilities;

• Availability of the system to train the operational and maintenance staff;

• Usage of standard repair and maintenance technologies with the involvement of Ukrainian enterprises;

• Big experience in construction of power units with VVER-1000.

Based on the received analysis, the main variants of the choice are the reactor facilities, based on the VVER-1000 technology are as follows:

• Modernized VVER-1000, analogue of the NPP “Temelin”, Check Republic;

• Design B-392B (Balakovskaya NPP);

• Design Belene 87/92 (B-466), Bulgaria.

Design “Modernized VVER-1000, analogue of the NPP “Temelin” was developed based on the technical decisions of the power units of “Temelin” NPP within the tender bid of the alliance “Skoda-YM” – “Westinghouse” for the completion of Belene NPP (Bulgaria). The main advantage is the use of the existing construction part and of the supplied equipment in compliance with the national safety norms with the consideration of IAEA and EUR requirements. These requirements are ensured by safety improvement measures, implemented at Temelin nuclear power units, as well as by the system, preventing the core melting.

Design B-392B is the adaptation of the conceptual design “AES-92” («АЭС-92») to the power unit 5 of the Balakovskaya NPP and possesses a number of improvements based on the analysis of the operating experience and IAEA recommendations for operating NPPs with VVER-1000.

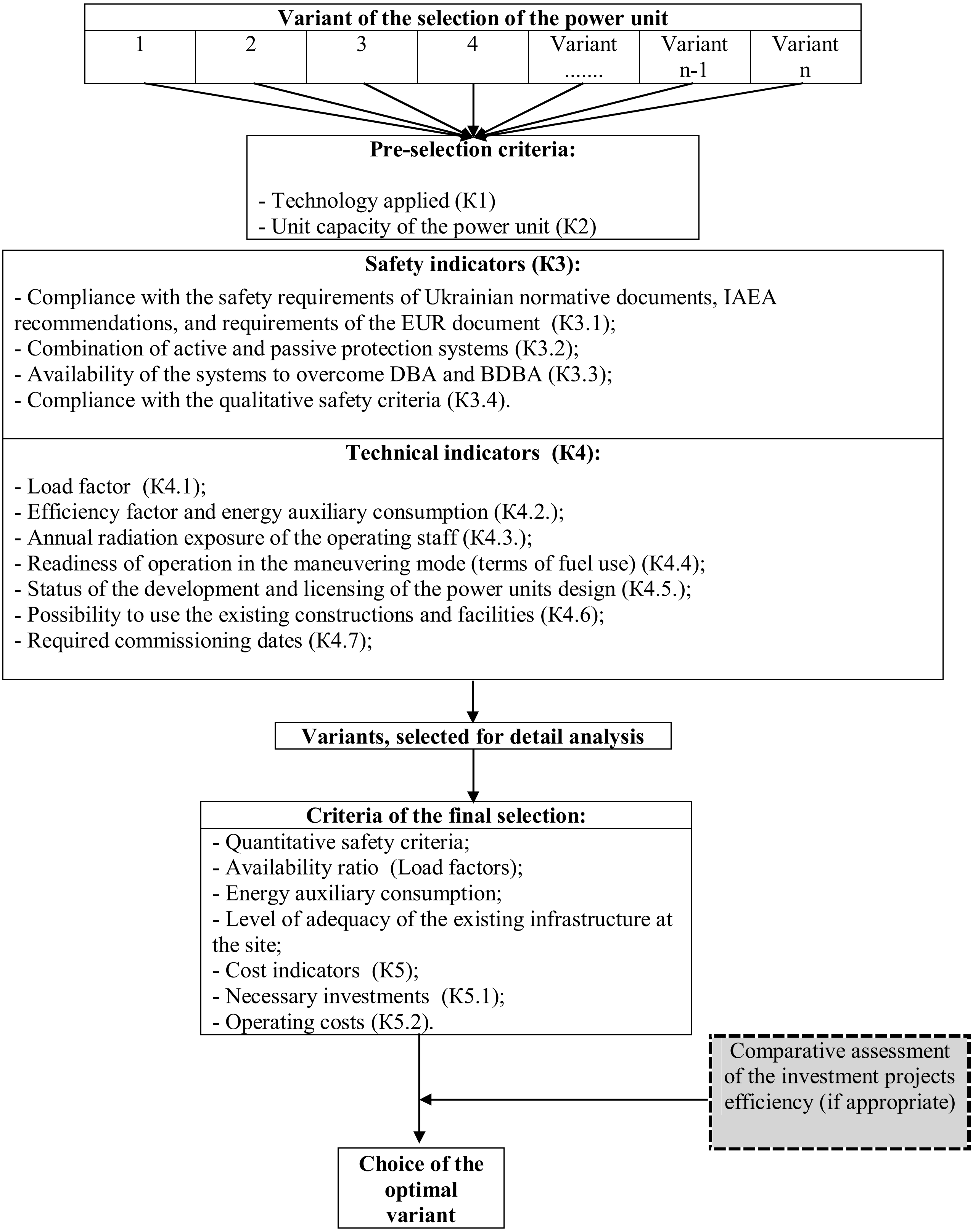
They comprise the improved reactor and the protection system, better equipment of the power units, upgraded main circulation pipe GTsN-1391 (ГЦН-1391). Safety systems with the extension of functions of passive systems have been improved; the measures to prevent damages of the main circulation circuit and related systems have been foreseen. Equipment layout does not require serious changes of the buildings, infrastructure, update of the systems and equipment; a part of the equipment, delivered to the site, is in use.

Design Belene 87/92 (B-466), also based on the design “AES-92”, is being implemented for the completion of Belene NPP, Bulgaria.

Technical peculiarities of the Belene NPP are as follows: the improved and additional safety systems, in comparison with the serial VVER, are applied; the reconstruction of the reactor compartment and manufacturing of the new equipment will be required for their accommodation, which shall result in a significant rise in cost of the design.

International experience of distribution of activities is applied in the design: AREVA, Alstom, Skoda and other leading western companies are involved in the project as the suppliers of the equipment, of the design and engineer works.

4 Analysis algorithm during the selection of the optimal power unit



5 Basic criteria of the power unit selection

№	Criteria Code and Title	Criterion
1	К1. Technology applied (PWR or BWR)	Initially during the selection of the alternative variants according to the power unit types for KNPP-3,4 it was considered to focus on light-water reactors (LWR) of the PWR type (pressurized water reactors)
2	К2. Unit capacity of the power unit	According to the information of UkrESP, the unit capacity of the power units KNPP-3,4 in the amount of 1000 MW is in compliance with the system requirements.
	К3 Compliance with the safety criteria and principles	
3	К3.1.1. Compliance with the safety criteria and principles of Ukrainian normative documents	Compliance with the safety criteria and principles, regulated by the Ukrainian normative documents (ND) in the NPP design sector
4	К3.1.2. Compliance with the IAEA recommendations, and with the requirements of the EUR document	Power units' compliance with the IAEA regulations will be established based on the analysis of their compliance with the requirements of the EUR document (European operating organizations), which includes these requirements.
5	К3.2 Combination of active and passive protection systems	The use of the interredundant active and passive systems and active systems with the components of the different design.
6	К3.3 Availability of the systems to prevent development of DBA into BDBA and mitigation of the BDBA consequences	Availability in the power unit design of the systems to prevent development of design-basis accidents (DBA) into the beyond design-basis accidents (BDBA) and mitigation of the BDBA consequences/control
7	К3.4 Qualitative safety criteria	Probabilities of the severe core damage (SCD) and maximum permissible accident discharge (MPAD), which for the newly designed power units in Ukraine make 10^{-5} and 10^{-6} per reactor/year, respectively (OPBU-2000)
8	К3.5 Safety improvement in comparison with the operating and power units under construction	The criteria of the choice of the new type of power unit lies the fact how much its safety level is higher than the safety indicators of the operating power units
	К4 Technical indicators	
9	К4.1 Load factor *The availability ratio to bear the nominal electrical load (Kg)*	Target value of the average annual availability ratio is not less than 90%.
10	К4.2 Efficiency factor and energy auxiliary consumption	Efficiency factor is at the level of 34-35% Energy Auxiliary Consumption ,EAC.=6,0-6,3%
11	К4.3 Annual radiation exposure of the operating staff	Limit of individual annual dose on exposure for persons of the category A (operating staff) is 20 mSv/year (NRBU-97).

№	Criteria Code and Title	Criterion
12	K4.4 Terms of fuel use	• Capacity regulation range – 25 ÷ 30%; • Load change speed– 5 ÷ 7 MW/min; • Participation in the diurnal regulation of the load curve. Considering perspective tendencies: • The power unit shall be able to operate in the range of loads from nominal to minimal; • Load change speed shall make 3% from the rated load/min. Higher speeds can be accepted upon agreement between the operators of the power units and of the energy system; • Number of loading cycles shall make: - 2 a day; - 5 a week; - Total a year - 200.
13	K4.5 Status of the development and licensing of the power units, availability of construction analogues	Existence in the world of the operating NPPs or NPPs under construction with the similar power units or the status of licensing of the NPP design with the reactors of this type. Status of the development, construction and licensing of designs
14	K4.6 Possibility to use the existing constructions and facilities	1 Use of the existing facilities of the power units 3,4 2 Interconnection with the existing infrastructure (including nuclear fuel and radioactive waste) 3 Possibility to use critical equipment, at the time purchased for KNPP-3,4
15	K4.7 * Guarantee of the scheduled commissioning dates	Power unit №3 – 2015 Power unit №4 – 2016
	K5 Cost indicators	
16	K5.1 Capital investments	Target indicator of ratio of capital investments is about 2000 USD/KW
17	K5.2 Operating costs	Total amount of fuel and operating net cost components, value whereof for the purposes of this work is assumed at the level of 1-2 US cents/KWh*

** - Construction cycle of a power unit is 7,5-8 years. Duration of the construction from the laying of the first concrete up to commissioning is 3 - 6 years. In order to guarantee commissioning of the power unit 3 in line with the "Strategy…" in 2015 and power unit 4 in 2016, it is required to hold tenders in 2007 for FS elaboration, equipment supply and design. Elaboration of the design and of the working documentation must be initiated not later than beginning 2008.*

6 Alternative variants under review

№	Reactor	Supplier	Capacity and technology	Basic characteristics, distinctive feature
1	B-320 VVER-1000	OKB GP,	1000 MW VVER	Unified design of the power unit VVER-1000 (base technology)
2	B-320 VVER-1000 Skoda-Belene	OKB GP Skoda YaM	1000 MW VVER	Upgraded RF VVER-1000, analogue of the NPP "Temelin", developed for tender in NPP Belene, with the improved safety indicators and with the system of reactor bottom cooling. Meets the requirements of EUR.
3	B-392 VVER-1000 (AES-92) (B-466, B-412, B-428)	OKB GP, ATEP, Russia	1068 MW	VVER-technology with passive safety systems and elements, improved for the design AES-92 Concept of the design AES-92 is the basis of the developed and implemented designs RF B-412 (India), B-428 (China) and B-466 (Bulgaria)
4	B-392Б VVER-1000	The same	1068 MW	RF based on B-392, upgraded for conditions of the power unit 5 of Balakovskaya NPP (integration into a new construction part of the design B-320), with double containment.
5	System 80+ /APR-1400	Westing-house (BNFL) successor ABB-CE USA	1300 MW Of the PWR type	Improved design in compliance with the ALWR requirements. The design was certified by NRC in May 1997. NPPs, based on this design, are built and in operation in USA and Korea. Korean company Doosan under the license of Westinghouse used this model to create their own reactor APR-1400. 2 power units of this type are planned to be commissioned in 2010/11
6	AP1000	Westing-house USA	1050 MW Of the PWR type	Improved reactor with passive safety systems. Safety assurance is based on the use of passive principles and systems.
7	EPR	Framatome ANP, France-Germany	1550 MW, Of the PWR type	Evolutionary RF design, developed based on the previous model N4 of the company Framatome, and the reactor Konvoi of the company Siemens. It meets the requirements of German, French and Finnish regulatory documents and EUR requirements. Is being constructed at Olkiluoto NPP (Finland)

The basic factors, which predetermined this very set of variants are as follows:

- Already existing positive experience of operating of NPPs with some of these reactors;
- Recognized by the international nuclear community high level of readiness of the designs of some of the reviewed power units to their practical implementation in a number of countries, and in a short time;
- Their recognized by the regulatory authorities of a number of countries compliance with the criteria and norms of nuclear and radiation safety, effective in these countries;
- All variants comprise the so-called evolutionary designs, which use reliable and safe technical solutions, which proved to be good in operation.

Analysis of full value of the variants for compliance with the specified criteria is complicated, among other factors, by the presentation or advertising nature of the available information. It also shall be mentioned that the criteria were not ranged according to their influence on the result of the analysis; that is the respective "specific weight" was not assigned to them.

According to the degree of conformity of the specified selection variants aggregate are the following power unit designs:

- According to the group of power units designs, created based on the VVER technology of the Russian design – evolutionary designs of the power units of the 3rd generation:
  - Upgraded VVER-1000, analogue of the NPP “Temelin”, Check Republic;
  - Design B-392B (Balakovskaya NPP).
  - Design of the series «AES-92» - Belene 87/92 (B-466), Bulgaria;
- According to the group of power units designs, based on the western technologies (mainly PWR) – power unit design with the reactor:
  - AP1000
  - EPR.

Below there is a summary chart of variants of the power unit selection and a comparative chart of conformity of the specified selection criteria aggregate.

7 Consolidated comparative chart of design characteristics of the reactor models of the PRW and VRW types under review

Design characteristics	**B-320 – basic technology (VVER-1000)**	**B-320 (VVER-1000) Skoda-Belene**	**B-392 (VVER-1000), AES-92 (B-466, B-412, B-428)**	**B-392Б (VVER-1000) Bal NPP, II queue**	**System 80+/ APR-1400**	**AP 1000 Westinghouse USA**	**EPR Framatome ANP (European reactor)**
Reactor	PWR	PWR	PWR	PWR	PWR	PWR	PWR
Chief designer	Hydro-press (ATEP)	Hydro-press	Hydro-press (ATEP)	Hydro-press (ATEP)	Westinghouse (BNFL) successor ABB-CE, USA	Westinghouse, USA	Framatome ANP, France-Germany
Electric power, MW (net)	1000	1000	1068	1068	1300	1150	1600
Thermal power, MW	3000	3000	3000	3000	3817	3400	4270
Coolant type	H2O	H2O	H2O	H2O	H2O	H2O	H2O
Fuel material / enrichment with the isotope U235	UO2 / 4.4	UO2 / 4.4	UO2/ 4,1	UO2 / 4.28	UO2 and/or PuO2	UO2	UO2 or UO2/PuO2
A number of fuel assemblies	163	163	163	163	241	157	241
A number of control rods	61	61	121	121	93	53 «black» 16 «grey»	89
Height/diameter of the reactor vessel, м	10.885	10.885	11.185	11.185	5.3/4.6 (inside)	12.06/4.47	12.8/5.25 (outside diameter)
Average density of energy release, KW/l	109	109	109	448 W/sm	95.5	96.2	155 W/sm
Coolant temperature at the inlet, °C	290	290	291	291	292	287	295.6
Coolant temperature at the outlet, °C	320	320	321	321	324	325	327.3
Coolant pressure, MPa	15.7	15.7	15.7	15.7	15.41	15.51	15.51
Containment	Single containment	Single containment	Double containment: inside – leak-proof, outside – protective	Double containment: inside – leak-proof, outside – protective	Double containment: spherical steel with the outside protective ferroconcrete	Double containment: spherical steel with the outside protective ferroconcrete	Double containment
Availability of the system to isolate core melting	no	Water system of the reactor bottom cooling	yes	no	no	Water system of the reactor vessel cooling	yes
Working cycle between refueling, months	12	12	12	12	18-24	17	12-24
Refueling duration, days	28-30	28-30	25	16	16.8	16	16
Fueling, tons			80 t U		data not available	data not available	141
Estimate annual radiation exposure of the operating staff, per reactor	20 mSv	20 mSv	20 mSv	20 mSv	<70 mSv	<70 mSv	<100 mSv
Number of loops	4	4	4	4	2	2	4

Design characteristics	B-320 – basic technology (VVER-1000)	B-320 (VVER-1000) Skoda-Belene	B-392 (VVER-1000), AES-92 (B-466, B-412, B-428)	B-392Б (VVER-1000) Bal NPP, II queue	System 80+/ APR-1400	AP 1000 Westinghouse USA	EPR Framatome ANP (European reactor)
Power of the residual heat removal	ECCS active part: 3x100% Passive part: 4 ECCS accumulators	ECCS active part: 3x100% Passive part: 4 ECCS accumulators	ECCS active part: 4x100% Passive part: 4 ECCS accumulators, SPOT-4x33%, DSP ZAZ-4x33%	ECCS active part: 3x100% Passive part: 4 ECCS accumulators, SPOT -4x33%, DSP ZAZ -4x33%	ECCS active part: 4x100% Passive part: - data not available	Safety system: 4x50% with the Emergency feed water system and 100% standby - blowing/makeup; normal operation system - 2x50%	ECCS active part: 4x50% АПВ Passive part: 4 Hydro accumulators
Consideration of the principle "lead before break"	Not considered	data not available	Considered	Considered	data not available	Considered	Considered
Core damage frequency, 1/reactor*year	<8.3*10-5	<2.3*10-6	<2,46*10-7	<4.3*10-7	<1.0*10-6	<1.7*10-7	<1.0*10-7
License for the construction commencement	yes	yes	yes	yes	data not available	data not available	yes
Design certificate/license	yes	yes	yes	yes	yes	yes	yes
Design service life, years	30	40-60	40-60	40-60	60	60	60
Construction duration, years	6	6	6	6	4	3	5
The average speed of fuel burn, MW*day/kg (U)	40.2	40.2	43	43	65	data not available	60
Efficiency factor, net, %	data not available	33	33.1	35	data not available	32.7	36.0-37.0
Electric power consumption for auxiliary,%	6.85	6.85	data not available	5.90	data not available	data not available	data not available
Availability ratio, %	80.6 (Load factor=80)	~80	Load factor =90	Load factor=84 with the increase up to 90	~92.0	≥93.0	92.0

1. **"?"** data, received from bare sources, raise certain doubts;

8 Summary comparative chart of the conformity of the power unit type with the specified selection criteria

Reactor		B-320	B-320 Skoda - Belen	B-392 B-466, B-412, B-428	B-392Б	B-392M (B-466П)	System 80+/ APR-1400	AP1000	EPR
Criteria	**Код**	**Conformity with the selection criteria (+/-)**							
Technology applied	К1	+	+	+	+	+	+	+	+
Unit capacity of the power unit	К2	+	+	+	+	+	+	+	-
Safety indicators	К3.1								
- Compliance with the requirements of Ukrainian normative documents	К3.1.1	+	+	+	+	+	?	+?	+?
- Compliance with the IAEA recommendations	К3.1.2	+	+	+	+	+	+	+/-	+
- Compliance with the requirements of the EUR document	К3.1.3	-	+	+	+	+	?	+/-	+
- Combination of active and passive protection systems	К3.2	+	+	+	+	+	+	+	+
- Availability of the systems to overcome DBA and BDBA	К3.3	+	+	+	+	+	+	+	+
- Compliance with the qualitative safety criteria	К3.4	+	+	+	+	+	+	+	+
Technical indicators:	К4								
- Load factor / availability ratio	К4.1	-	+	-	+	+	+	+	+
- Efficiency factor and energy auxiliary consumption	К4.2	-	-?	+?	+	+	+	+	+
- Annual radiation exposure of the operating staff	К4.3	-	+	+	+	+	+	+	+
- Possibility to operate in the maneuvering mode (terms of fuel use)	К4.4	-	-?	-	+	+	+?	+	+
- Status of the development and licensing of the power unit design	К4.5	+	+	+	+	+/-	+/-	+/-	+/-
- Possibility to use the existing constructions and facilities	К4.6	+	+	+/-	+	+/-	-	-	-
- Required commissioning dates	К4.7	+	+	-?	+	+	+	+	+
Cost indicators:	К5								
- Required Capital investments	К5.1	+/-	+/-?	+	+	+	+	+	+
- Operating costs	К5.2	-	-?	-	+	?	+	+	+

9 General conclusions of the tentative analysis

According to the conformity of the aggregate of technical and economical criteria and safety criteria, the most efficient for KNPP-3,4 conditions is the variant to construct the power unit with the reactor facility based on the evolutionary design VVER-1000. It is necessary to take into account social and economical facts of the implementation of the high-tech design by the national industry.

Principle benefits, which define such choice, are as follows:

- Compliance with the requirements of Ukrainian regulatory documents.
- Possibility to achieve compliance with the IAEA and EUR requirements.
- Economical efficiency:

- possibility to use the ready-made construction part of the power units 3,4 and the existing infrastructure;
- maximum participation of the Ukrainian side and, in this connection, development of industrial and energy complex and economy of Ukraine.