AES-92 for Belene: The Mystery Reactor

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Summary

Bulgaria decided at the end of 2006 to build a nuclear power plant in Belene. Atomstroyexport (ASE[1]) won the tender with a reactor model called AES-92[2]. The AES-92 is an updated VVER 1000/320[3], which is the Soviet-type pressurized light water reactor known in Russia as the third-generation VVER 1000 reactor (alias VVER-1000/V392). ASE intends to deliver two of these 1000 MW reactors to Bulgaria.

But what exactly is the AES-92? It is difficult to get reliable technical facts about this reactor, which is not being publicly advertised by the Russian nuclear industry. There is no operational experience with this reactor. Research for this fact sheet showed that the AES-92 is a customized VVER-1000/V-392 model known under many confusing abbreviations. Only one very similar type was built in China (called AES-91, also based on the VVER 1000/320 series). However, there is no operational experience with this AES reactor either (NPP Tianwan-1/2, installed capacity 2x1060 MW, design life 40 years), since the first unit went into full power operation only in January 2007. It is also not realistic to think that there will be reliable information regarding operational experience available within the next few years for the Chinese reactor. In addition, there is no safety assessment on this reactor model available.

The Chinese AES-91 or 92 (VVER-1000/V-428 according to the Russian engineering company Gidropress) was developed on the basis of the design V-392. According to information of Gidropress, who is responsible for the design, the Chinese reactor fulfils the recommendations of the IAEA programme on upgrading and improving safety of operating VVER-1000 reactors.

The only other comparable reactor, although of a slightly different design, is the AES-91 at Kudankulam in India. This AES reactor is currently under construction and therefore does not provide any data on operational experience. Another AES model, carrying the same number und name as is used in the Belene EIA documentation, is under construction at the Bushehr site in Iran.

Soviet reactor in the EU

If Bulgaria's National Electricity Transmission Company (NEC) and the Bulgarian government succeed in their plans, soon there could be one more of the mysterious AES reactors - in an EU country with the support of EU money (via EURATOM loan). For the Russian nuclear industry this project is crucial – it hopes to return to the European market.

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[1] ASE, a joint stock company is a merger of Atomenergoexport and Zarubeshatomenergostroy. AES is responsible for the export activities of the Russian nuclear industry.

[2] AES = Atomnaja Electrostancija (translates into "nuclear power plant")

[3] VVER = Vodo vodinoj energeticeskoj reactor (pressurized water reactor; water-cooled, water-moderated)

Bulgaria is an EU member state since January 2007 and therefore should comply with EU safety expectations. NEC is aware of this and declared that one reason for the choice was that a third-generation VVER was better accepted in the European Union than the VVER 1000/320 (e.g. Temelin in the CR), where the basic design dates from Soviet times. (NW 2006, No. 44). With third-generation VVER they mean the AES-92.

The EU does not have common safety standards, however, the AES-92 claims to meet the European Utilities´ Requirements for safety and reliability (NW 2006/50). According to the Bulgarian Nuclear Regulatory Authority (NRA), the NPP Belene should be licensed according to the new Western European Nuclear Regulators' Association (WENRA) reference safety levels for existing plants, which are still in discussion by WENRA.

Why has Russia won the Belene tender?

In the EIA for Belene NPP seven different reactors have been compared concerning the environmental impact: the Westinghouse AP 1000, CANDU-6 by AECL, two bids came from AREVA ANP, which are the EPR and the SWR, Skoda's VVER 1000/320, the Russian company ASE proposed also two types, the VVER 640/V-407 and the VVER 1000/V-466 (AES is not mentioned in the EIA).

The information provided in the Belene EIA documentation allows an assessment by comparing the technical data of these 7 proposed reactors. Since the majority of the proposed reactors are new and/or have never been built, there is not enough operational experience available and the data provided by the vendors have to been seen as more or less credible and reliable. While Western companies present fairly comprehensive descriptions of the reactors on their websites, Skoda and ASE provide only little information to the public and no safety assessment on this reactor is available.
The Russian bid for two third-generation VVERs of the V-466 model (= AES 92) promised a higher level of safety and a longer operating lifetime (60 years) than the competing bid from Skoda Alliance. The company ASE bid was also cheaper, 4 billion Euro compared to 5 billion Euro for Skoda Alliance. The main reason why the Russian offer this plant so cheaply is that the building site is not a green field, but an abandoned project that was launched in 1984 and terminated in 1991. By that time the scheme was 40% complete, with 60% of equipment already delivered, including a reactor, a steam generator and a turbine. It is this "starting capital" that dictated a low price of 2.6 billion Euros. (Novosti November 2006). ASE takes back the equipment delivered in the 1980ies to Bulgaria probably for use as spare parts in the old Russian VVER plants.

Celebrating the first commission to build a Russian reactor in the European Union, the Russian Information Agency Novosti praised the AES-92 reactor: “The project is a unique combination of active and passive safety systems, which guarantee maximum protection of the plant. Designers have anticipated the worst possible emergency scenarios, such as a sudden de-energizing of the plant, rupture of the reactor vessel, or even an aircraft crashing into the plant's building. One important feature of the design is the reactor building's double protective envelope - steel inside and heavy reinforced concrete outside. The centerpiece of the safety arrangement is the so-called trap for the active zone melt - an original and purely Russian idea” (Novosti November 2006). This system is different from the EPR core catcher: for ex-vessel core recovery a second vessel outside the main vessel is used - a simpler arrangement than the EPR's core-spreading system. Verification of the long term integrity is not proofed for both - thermochemical reactions with the molten reactor core which could lead to emissions are under investigation (Inside NRC 2006, No.13).

AES-92 - According to ASE representatives the AES-92 combines active and passive safety systems, features an "economically advantageous" safety systems organization, and uses instrumentation and control (I&C) of a new generation. Framatome ANP would supply the I&C system. (Teleperm system- originally by Siemens is used also on the Tianwan AES-92).

Framatome ANP will also deliver electrical systems, heating, ventilation, and air conditioning systems, safety systems including hydrogen recombiners and monitors, and containment pre-stress system - also similar to Framatome ANP's scope at Tianwan. (NW 2007 No.6)

Technical data of the EIA documentation confirm that the proposed AES-92 VVER 1000 reactor is in some parts improved compared to the VVER 320 reactor. The AES reactor has more backup systems for safe shutdown and cooling the reactor than the old VVER 1000 version. But a lifetime of 60 years is a challenge for the material, and it is not sure that it can be realized safely. It seems that critiques of the original VVER 1000/320 system by Western national regulatory authorities and technical support organizations have been considered in the new VVER 1000 design. However, it is not possible to assess the safety level of these reactors without more detailed information on the design and the material used for fuel rods, the reactor vessel and other components than was provided in the EIA documentation on Belene.

The VVER 1000 development

The Soviet VVER 1000 reactor was developed between 1975 and 1985:

First generation VVER 1000/V338 were built at Kalinin 1-2, and South Ukraine;

Second generation: All later VVER 1000 plants operating in Europe are of the VVER 1000/ V320 type (Balakhovo, Rovno, Khmelnitsky, South Ukraine, Zaporoshe, Kosloduy5/6). Temelin in principle is also a **VVER 1000/320 –** designed in the Soviet Union, constructed by Skoda and modernized with Western I&C system by Westinghouse. But Temelin NPP was not the only NPP cooperation of Russian and Western NPP developers.

Third generation VVER 1000 / V- 392: New design features of VVER 1000 reactors were developed by the Russian reactor design and construction company GIDROPRESS in cooperation with western institutions. The cooperation concerned in particular the safety improvement, the involved institutions and enterprises were SIEMENS and GRS from Germany; FRAMATOME and ELECTRICITE DE FRANCE International from France and Fortum Engineering Ltd. from Finland. The outcome are the following improved VVER 1000 reactors:

VVER 91: In 1989 Finland and the Soviet Union started a development project for a VVER 1000 version that would meet stringent Finnish nuclear design requirements. “on paper, the Soviet VVER 91 design is among the world's most advanced light water NPPs” (NEI 1997).

VVER 92: Development of a new VVER-1000 design, the VVER-92, was expected to be carried out with Western assistance. (NEI 1997) and deliver a NPP which should be cheap, simple and safe. “The VVER-92 incorporated what one Finnish nuclear expert called “radically simplified” plant systems that included active safety systems, a reduced-power reactor core, and a double containment structure surrounding the nuclear reactor.” (NEI 1997)

The multitude of type denominations is not helpful to identify the different designs of VVER 1000. But probably all the new VVER-1000 projects, whatever their number may be, are derivations of the VVER 1000/ V320 (generally called VVER 1000/V392 - even if they are not named VVER but AES). None of these VVER 1000/V392 reactors has been built in the Russian Federation – the first completed unit of this type is unit -1 of NPP Tianwan in China, the second unit of this NPP is scheduled to be finished this year.

AES 91 in India (or VVER-1000/V-412)

According to the designer, the Russian engineering company Gidropress, the main equipment is being developed on the basis of design VVER1000/ 392. Customer's additional requirements, caused by specific features of the object, were considered in the design. The main points of these requirements are:

- expansion of spectrum of design basis and beyond design basis accidents;
- application of traditional active safety systems in addition to passive safety systems;
- consideration of seismic impacts, corresponding to NPP "Kudankulam" site;
- consideration of the requirements for power Unit load-following specific for NPP "Kudankulam". (GIDROPRESS 2007)

The first unit of Kundakulam NPP is scheduled for start operation in 2007.

AES 91 in China (or 92 or VVER -1000/V-428)

According to the designer, the Russian engineering company Gidropress, the main reactor equipment is being developed on the basis of design V-392. During development of the design the corresponding measures from the program on upgrading the operating WWER-1000 and IAEA recommendations on improving safety of the operating WWER-1000 were considered. It is unclear what passive safety systems were not applied because China did not consider them necessary or whether they were replaced with something else, when Gidropress continues saying that: `Unlike design V-392 the improvement of reliability, safety and economical characteristics of the plant is performed in compliance with the Customer's requirements **without using additional passive safety systems provided in design V-392** on the basis of:

- expansion of spectrum of design modes in comparison with the reference power unit (design V-320) and consideration of beyond design basis accidents in the design;
- application of new, advanced I&C systems and use of hardware for management of beyond design basis accidents.

The reactor VVER 1000/V-428 in China is designed to resist seismic impact under operating basis earthquake of magnitude 7 according to MSK 64 scale and safe shutdown earthquake of magnitude 8 according to MSK 64 scale.´ (GIDROPRESS 2007)

TIANWAN NPP

NPP Tianwan is the first unit of the new series, which came into operation. The Russian AES-91 type unit is an improved concept based on the experience of design, construction and operation of WWER-1000/320 series, absorbing the advanced technologies from western PWR, conforming with the existing international requirements in nuclear and radiation safety. The plant also adopts integrated digital I&C system of Siemens, Germany.

According to the Chinese Atomic Energy Authority the construction cost per kilowatt and operation cost of the project are being kept low, NPP Tianwan has an installed capacity of 2x1060 MW, design life of 40 years, the annual average load factor is no less than 80% and annual generated electricity 14 billion kWh. (http://www.caea.gov.cn/n602670/n621903/n621904/67770.html). Inspite of this optimistic presentation, construction was not kept: Planned construction time of Tianwan NPP-1 was planned to be 62 month. It started in 2000 and became operational in January 2007-this is a delay of at least 1 year.

AES-92 (or VVER -1000/V-466) in the Islamic Republic of Iran.

According to information by Gidropress the main reactor equipment is being developed on the basis of design V-392. Results of the examination of KWU equipment at NPP “Bushehr” Unit 1, used as a part of the project of the Unit completion, are considered in development of reactor V-446 design. The design is in compliance with the stringent requirements of the Customer for seismic stability.

The latest Gidropress development is a reactor of an even bigger capacity - 1500 MW electrical output (VVER-1500 /V–448). More technical info by the designer:
(GIDROOPRESS, website http://www.gidropress.podolsk.ru/English/v_392_k.html)

AES-2006

The next plants announced to be built in the Russian Federation is the AES-2006. According to Rosatom [4] the AES-2006 is a VVER 1200 reactor i.e. a PWR with 1200 MW electrical output. Currently two VVER 1200 units are planned for the NPP Leningrad II, a site near Sosnovy Bor. Rosatom describes these reactors as an evolutionary development of the VVER 1000 in Tianwan/China (a VVER of Generation III). Rosatom's deputy director general announced that the design carried out by Gidropress will be ready by June. The reactor is planned for 50 years of operation. Capital cost is estimated to be 1200 US$ /kW installed and the projected construction time is 54 month. (NW 2007 No.6)

SAFETY LEVEL OF AES REACTORS

Russian industry announced, that AES-92 is a VVER 1000 reactor with a modern design that has met European Utilities' Requirement for safety and reliability (NW 2006 No 50.) This claim was not proven yet, because hardly any documentation is available. However, the same goes for the EPR, because none is in operation yet and many technical data are not public.

But usually the buyer of a reactor gets a lot more information from the vendor. The Finnish nuclear authority STUK for example published in 2005 its assessment of the Preliminary Safety Report of the EPR, wherein results of the preliminary PSA and safety relevant design problems are discussed.

What is known are the safety targets of the IAEA, of WENRA[5] and the safety and reliability criteria that the big utilities in Europe expect new reactors to achieve, but all this targets are recommendations only and there are no binding obligations, besides the national nuclear law.

The **European Utilities' Requirements (EUR)** contain several safety and reliability criteria, of which only some safety criteria are presented here as an example:

1. **Accidents with limited impact** shall generate a maximal release of 0,1% of core inventory: I-131: 4000 TBq Cs-137 ~400 TBq, Sr-90 ~100 Tbq.

2. **Probabilistic Safety Criteria** (PSC) of **European Utilities** are more restrictive than the criteria of the IAEA.

   EUR Probabilistic Safety Targets:
   - core damage frequency: < 10 E-5,
   - frequency of release > limited impact: 10 E-6,
   - early or large release frequency: 10E-7

[4] The Federal state unitary enterprise “Russian state concern for electrical and heat energy production in nuclear power plants” (“Rosenergoatom” concern)

[5] Western Nuclear Regulatory Authorities

Other important safety targets are the IAEA recommendations:

IAEA Probabilistic Safety Targets:

- Core damage frequency (CDF): 1E-4/reactor year for **existing plants**,
- CDF: 1E-5 per reactor year for **future plants**
- Large release frequency (LRF): 1E-5/reactor year for **existing plants**.
- LRF: 1E-6/ reactor year f**or future plants**

(INSAG 3, 1999)

Most concrete information on the AES-92 reactor is contained in the EIA documentation for Belene NPP (see Annex 1). From these data we conclude that the implementation of more redundant and diverse safety systems compared to VVER 1000/ V320 is planned. It appears that the critique of GRS and WENRA of the older VVER 1000 design has been taken into account by the designers of AES-92 and they tried to implement it in the new VVER 1000 reactor. However, without having any access to a detailed technical description and to the preliminary safety assessments of the AES-92 it is impossible to evaluate the credibility of the data concerning severe accidents (frequency and release risk) presented in the EIA – which seems to be underestimated.

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ANNEX 1

Technical Data VVER 1000/V466 (BELENE EIA- Documentation)

Capacity: thermal 3000 MW
electrical 1068 MW

Lifetime: 60 years (compared to 30-40 years for V320)

expected to be operational 7900 hours/year

Primary coolant circuit:

number of loops: 4
coolant flow rate through the reactor: 86000 m³/h
pressure (operational) 15,7 MPa (design – max.17,6)
coolant temperature: inlet 291°C, outlet 321 °C

reactor core: 80t U
fuel = VVER 1000 163 fuel elements (hexagonal), enrichment 4,28%
average fuel burnup: 47,2 MWd/kgU (max. 49,9)
fuel cycle: 3-4 years
(burnup slightly higher than V 320 with less uranium)

Secondary circuit :
pressure: 6,28 MPa

Safety systems:
active HPSI. LPSI, SS, EFWS: 4*100%
passive 2 systems, 4*33% per system

(improvement compared to V 320)

Containment:

65000 m³ (slightly bigger than V320)

Design parameters: airplane crash 5t/120m/s 20t/215m/s ... shock wave 30kPa 1 s
earthquake: max. acceleration: 0,25 g (improvement compared to V320)

maximal design base: 1200° cladding tube temperature maximal 18% damaged fuel elements

maximal DBA: LRF 1E-4 resulting in an effective dose of 0,1 mSv for the public

PSA: CDF: < 5 E-6 LRF: < 1E-8 resulting in an effective dose of <50 mSv for the public

Abbreviations / Glossary

ASE	Atomstroyexport – Russia nuclear technology exporter
EIA	Environmental Impact Assessment
AP 1000	currently available LWR reactor by Westinghouse
AECL	Atomic Energy of Canada Limited
LWR	Light Water Reactor
EPR	European Pressurised Water Reactor, the currently available LWR with 1,630 MW by Areva
SWR	currently available new Boiling Water Reactor by Areva (SWR-1000)

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