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(1991 and the Future)

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1991 and the Future

MOSCOW 1992

Atomic Energy Ministry of the Russian Federation

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Technicoeconomic specifications of nuclear power plants with RBMK reactors (1991 and the future):

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Data are considered on the contribution of nuclear power plants with RBMK reactors (Chernobyl-type nuclear power plants) to the production of electrical energy in the Russian Federation and the former USSR in 1991 and in previous years. Their operating characteristics are analyzed: annual energy production; unplanned shutdowns; annual and cumulative installed capacity utilization factors (ICUF) [KIUM]. A comparative analysis is made of the characteristics of nuclear power plants with RBMK and with VVER

reactors and of those of foreign nuclear power plants. The economic effect of operation of power units with RBMK is assessed. An overview is offered of means of financing their redesign and modernization. Renovation of nuclear power plants with RBMK reactors through gradual replacement of their facilities with MKER-800 channel-type water-graphite reactors is examined.

Tables 6, Fig. 2, list of references 4 - Technicoeconomic specifications of nuclear power plants with RBMK reactors (1991 and the future).

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1. INTRODUCTION

The post-Chernobyl period in the nuclear power industry has been characterized by an increasingly negative attitude toward it on the part of the scientific and technical community, particularly toward one of the two main trends in the nuclear power industry in the former USSR: nuclear power plants with RBMK (Chernobyl-type) reactors.

During the years since the accident at Chernobyl its causes have been thoroughly analyzed [1], and the measures that have been taken to increase the safety of RBMK reactors have completely eliminated the possibility of recurrence of an accident according to the Chernobyl scenario, which involved instantaneous neutron runaway, i.e., the release of significant quantities of radioactivity. The redesign and modernization of nuclear power plants with RBMK reactors is continuing. Nevertheless, the prejudice remains against them, and against channel-type water-graphite reactors in general, and decommissioning of some active power units ahead of schedule is being considered. The latter possibility, clearly, does not take into account the economic and social problems associated with such a decision.

The low level of domestic general industrial technology and product quality as compared with the level abroad is not a secret now. This problem, which the entire country shares, could not but affect reactor engineering, including nuclear power plants with RBMK reactors. Within the nuclear power industry this problem must obviously be solved expeditiously, because this

branch of industry poses a potential danger. Nevertheless, under existing conditions, given the existing quality of general industrial equipment, nuclear power plants with RBMK reactors are demonstrably safe and offer high operating characteristics at both domestic and worldwide levels. This is the result, above all, of several good design qualities of RBMK reactors, and is to the credit of the highly skilled operating personnel of nuclear power plants.

This work presents data on the contribution of nuclear power plants with RBMK reactors to the nuclear power industry and to electrical energetics, their operating characteristics in 1991 and in the preceding years, and considers certain technicoeconomic aspects of their future operation.

2. CONTRIBUTION OF NUCLEAR POWER PLANTS WITH RBMK REACTORS TO ELECTRICAL ENERGY PRODUCTION

In 1991 the production of electrical energy in the Russian Federation (RF) was:

at thermoelectric power plants -	759,450 billion kW/hr (72.54%);
at hydroelectric power plants -	167,574 billion kW/hr (16.0%);
at nuclear power plants -	119,984 billion kW/hr (11.46%);
Total:	1,047,011 billion kW/hr (100%)

Of all of the electrical energy produced in 1991 at thermoelectric power plants, the greater part (60%) fell to natural gas: 150 billion $m^3 \approx$ 20% of the yield of natural gas in the Russian Federation. 172 million tons cond. fuel gas, 46 million tons cond. fuel oil and 93 million tons cond. fuel coal were burned.

In 1990 58.9% of all energy produced in the former USSR was produced in the Russian Federation (there are no data for the USSR for 1991), which comprised 1,017,042 bil. kW/hr.

In 1991 the production of electrical energy in the Russian Federation increased by 2.95% in all over 1990, production by nuclear power plants by 1.4%. However, the proportion of nuclear power plants in the production of electrical energy decreased by 1.4% (relative). It can be said that against the background of general economic breakdown these indicators are not bad.

Nine of the fifteen nuclear power plants active in the former USSR are located in the Russian Federation, having total installed capacity of 20242 MW. Four nuclear power plants house thirteen power units with pressurized water reactors (VVER), with a total capacity of 8594 MW, and eleven power units with RBMK reactors and installed capacity of 11,000 MW are installed at three nuclear power plants (9,800 MW when taking into count administrative underestimation of nuclear power plant capacity); the Beloyarskaya NPP has one power unit with a 600 MW capacity fast breeder reactor, and the

Bilibinskaya NTEP has four EGP [expansion not known] power units with a total capacity of 48 MW.

The contribution of nuclear power plants to the production of electrical energy in the Russian Federation in 1991 (11.46%), as in the preceding years, was significantly lower than in industrialized countries where nuclear power is being developed. For example, in 1991 it was approximately 76% in France, 35% on average in the EEC countries, and approximately 20% in the United States. However, in the most industrially developed regions of the Russian Federation the percentage of electrical energy produced at nuclear power plants was significantly above average: 16.7% for the Volga Unified Energy System (UES) [OES] (nuclear power plants with VVER reactors); 21.7% for the Central UES (contributions of nuclear power plants with VVER and RBMK reactors 33 and 67%, respectively); 33.1% for the North-West UES (contributions of nuclear power plants with VVER and RBMK: 34 and 66%).

In the Russian Federation as a whole in 1991 the contribution of nuclear power plants with reactors of different types to the production of electrical energy was:

- nuclear power plants with VVER - 41% (45% capacity);
- nuclear power plants with RBMK - 55.7% (51.5% capacity);
- other nuclear power plants - 3.3% (3.5% capacity).

The percentage of electrical energy produced at nuclear power plants in the former USSR in power units of various types was:

- nuclear power plants with VVER - 44.8%;
- nucelar power plants with RBMK - 68%;
- other nuclear power plants - 100%.

Data on the production of electrical energy at nuclear power plants in the Russian Federation and the former USSR in 1991 are given in Table 1.

In the last five years (since 1987) eleven nuclear power plant power units were brought to nominal capacity (7 units in 1987, 1 unit in 1988, 2 units in 1989, 1 unit in 1990, none in 1991), with total installed capacity of 11500 MW.

Of those, two units were at nuclear power plants with RBMK: at Ignalinsk NPP (RBMK-1500, 1987) and Smolensk NPP (RBMK-1000, 1990).

Nine units were commissioned at nuclear power plants with VVER: two units at Balakovskaya NPP (1987, 1988); three units at Zaporozhets NPP (1987, 1987, 1989), and one unit each at Kalinin, Rovno, Khmel'nitskaya and South Ukraine NPP (1987, 1987, 1989).

Thus of the total capacity of nuclear power plants commissioned in the last five years, approximately 35% were in the Russian Federation. Of those,

in turn, only 9.0% is at nuclear power plants with RBMK reactors, the rest being at nuclear power plants with VVER.

Table 1

NPP in Russian Federation (RF)		Other NPP (Ukraine, Lithuania)	
	NPP with RBMK reactors		
Kursk	?2966	Chernobyl	14478
Leningrad	23109	Ignalinsk	17000
Smolensk	20707		
Total, RF:	66782	Total, others:	31478
Total NPP with RBMK reactors:		98260 (68% in RF)	
	NPP with VVER reactors		
Balakovskaya	15462	South Ukraine	16716
Kalinin	11779	Rovno	11389
Kola	11968	Zaporozhets	27084
Novovoronezh	10038	Khmel'nitskiy	5472
Total, RF:	49247	Total, others:	60661
TOTAL NPP with VVER reactors:		109910 (44.8% in RF)	
	NPP with non-serial reactors		
Beloyarsk	3670		
Bilibinskaya	295		
Total, RF:	3965		
TOTAL NPP in RF:	119990	TOTAL, others:	92139
	TOTAL: 212,080		

The commissioning of nuclear power plant power units during those years reduced somewhat the proportion of production by nuclear power plants with RBMK in the total energy balance of nuclear power plants in the former USSR (Table 2).

At the same time, when assessing the the contribution of nuclear power plants of different types to energy production two indicators should be kept in mind: the percentage of electrical energy produced and the percentage in total capacity. These indicators (considering the regulated capacity of RBMK) for all nuclear power plants of the former USSR in 1991 were:

- nuclear power plants with VVER:
  percentage of electrical energy 51.8%, percentage of capacity - 56%;
- nuclear power plants with RBMK:
  percentage of electrical energy 46.3%, percentage of capacity - 42.3%;
- other nuclear power plants:
  percentage of electrical energy 1.9%, percentage of capacity - 1.7%.

These indicators permit one to draw the following conclusions concerning the role of nuclear power plants with RBMK reactors. As compared with nuclear power plants with VVER reactors in the Russian Federation, given 14% greater capacity they have 36% greater energy production. For all

nuclear power plants of the former USSR; given 24% less capacity they have only 10.6% less energy production.

Table 2

Production of electrical energy at nuclear power plants of the former USSR in 1987-1991 (TWT/hr).

Type of reactor	1987		1988		1989		1990		1991	
	TW/hr	%	TW/hr	%	TW/hr	%	TW/hr	%	TW/hr	%
RBMK 1000,1500	91.0	48.7	103.8	48.1	104.2	49.0	101.5	48.0	98.2	46.3
VVER 440,1000	88.2	47.2	104.3	48.4	101.3	47.6	106.2	50.2	109.9	51.8
All NPP	186.9	100	215.7	100	212.6	100	211.5	100	212.1	100

3. OPERATING CHARACTERISTICS OF NUCLEAR POWER PLANTS WITH RBMK REACTORS

In accordance with accepted recordkeeping practices, active power plants have been compared on the basis of cost of electrical energy. Mean cost values of electrical energy for nuclear power plants and thermoelectric plants from 1981 through 1990, weighed for annual electrical energy production, were 0.96 and 0.94 kopecks/kW-hr, i.e., approximately equal.

Mean cost of electrical energy for the decade at nuclear power plants with RBMK reactors was 15% lower than at nuclear power plants with VVER.

This ratio was the result of lower capital investment in power units with RBMK reactors and higher installed capacity utilization factors (ICUF) [KIUM].

Since 1991, in connection with the transition to market relations, the change in economic methods, the lack of stable prices and hyperinflation, the cost of electrical energy as an indicator of comparative economic effectiveness has become increasingly meaningless.

Under these conditions, a technicoeconomic analysis of active nuclear power plants should be based, above all, on a set of economic indicators: ICUF, the number of violations in operation (with analysis of their causes), underproduction of electrical energy, and so on.

Table 3 presents the values of production of electrical energy and ICUF of all power units at nuclear power plants with RBMK in 1990 and 1991, cumulative (from the moment of power startup to the end of 1991) values of ICUF, and mean arithmetic and mean values of ICUF, weighted for capacity, for all power units with RBMK reactors.

Table 3

Operating indicators of nuclear power plants with RBMK reactors in 1990-1991

NPP (Country)	Unit	Date of power startup	Installed capacity/ regulated cap., GWxhr	1990 Production of elec. energy, GWxhr	1990 ICUF[1], %	1991 Production of elec. energy, GWxhr	1991 ICUF[1], %	Total production of elec. energy as of end 1991, GWxhr	Cumulative ICUF[2], %
Leningrad (RF)	1	12.21.73	1000/700[3]	0[5]	0	4367.5	71.2	105066.0	68.2
	2	07.15.75	1000/700[3]	6606.4	90.6	4936.3	80.5	109242.0	77.9
	3	12.07.79	1000	8203.9	93.7	7100.5	81.1	85719.3	81.1
	4	02.09.81	1000	8452.8	96.5	6704.4	76.5	78485.3	82.3
Kursk (RF)	1	12.30.76	1000/700[3]	5531.9	75.8	4600.0	75.0	93829.8	73.7
	2	01.28.79	1000/700[3]	5242.3	72.0	4839.5	78.9	80444.1	73.6
	3	10.17.83	1000	7483.0	85.4	5572.4	63.6	51095.4	71.1
	4	12.02.85	1000	6549.0	74.8	7954.0	90.8	41586.3	78.1
Chernobyl (Ukraine)	1	09.27.77	1000/700[3]	5648.4	77.5	4464.5	72.7	82493.1	68.2
	2	12.22.78	1000/700[3]	4811.5	66.0	3078.8	50.2	79951.2	72.6
	3	12.03.81	1000	6869.9	78.4	6571.6	75.0	56887.3	64.5
Smolensk (RF)	1	12.09.82	1000	6760.9	77.2	7235.9	82.6	58186.3	73.3
	2	05.04.83	1000	7253.7	82.8	6288.3	71.8	45784.5	78.6
	3	01.31.90	1000	5090.9	58.1	7313.9	83.5	12404.8	73.9
Total for all NPP with RBMK-1000			14000/12200	84504.5	73.5/ 74.2[6]	81027.6	75.2/ 75.8[6]	1013986.6	74 1/ 76 2[6]
Ignalinsk (Lithuania)	1	12.31.83	1500/1250[4]	8073.1	73.7	7405.4	67.6	53571.4	55.6
	2	08.27.87	1500/1250[4]	8958.9	81.8	9594.2	87.6	26746.2	55.3
TOTAL	16		17000/14700	101536.5	74.0/ 74.8[6]	98027.2	75.5/ 76.1[6]	1094304.2	71.8/ 74.1[6]

1) taking into account regulated installed capacity;
2) from moment of power startup;
3) capacity regulated since June 12, 1990;
4) capacity regulated since 1988;
5) shut down for redesign;
6) mean arithmetic value/ mean weighted for capacity

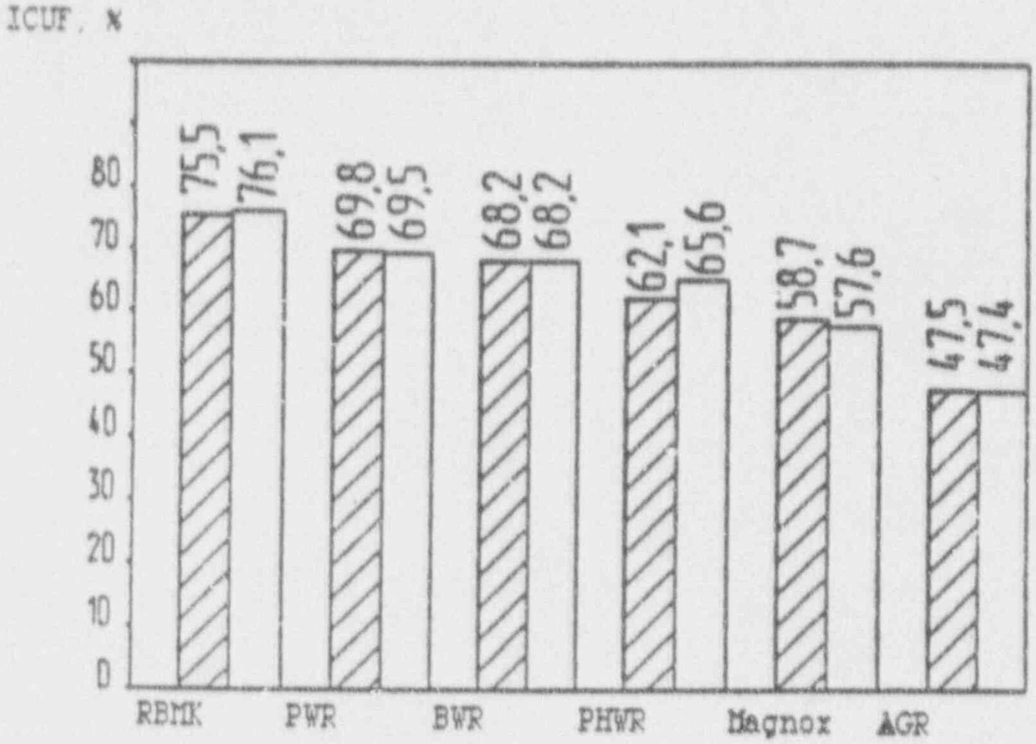

Fig. 1. Installed capacity utilization factor (ICUF) in 1990-1991 for NPP with .rious types of reactors

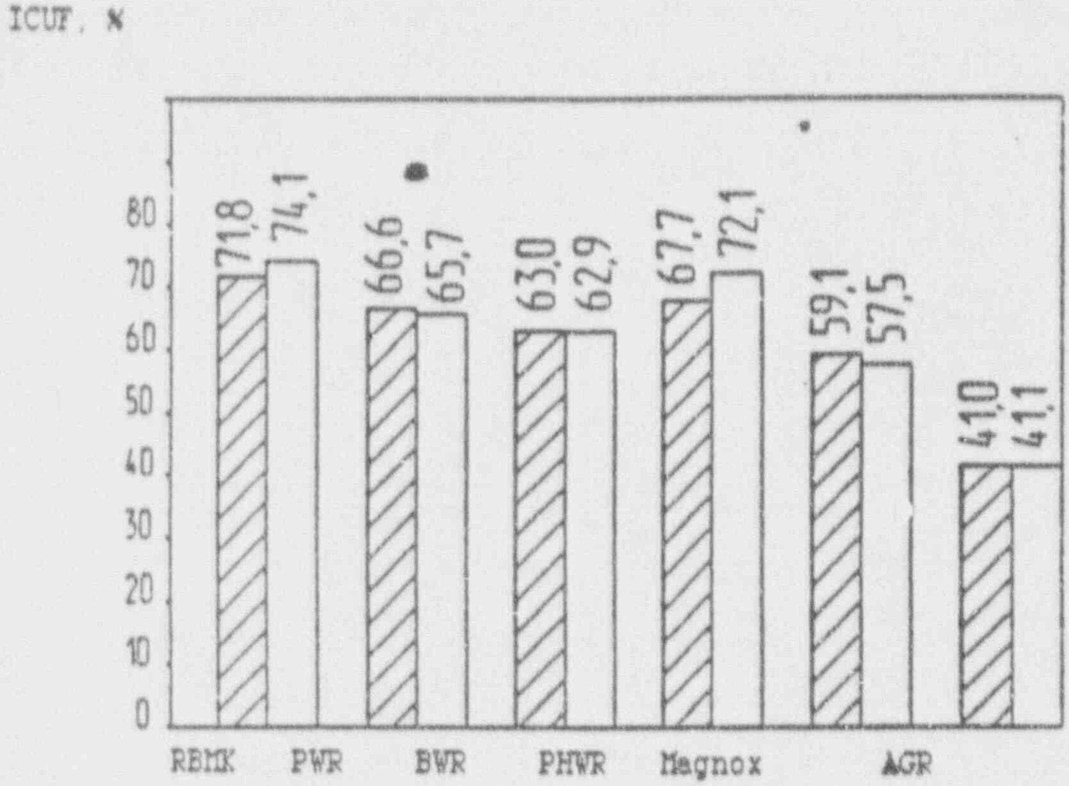

Fig. 2. Cumulative installed capacity utilization factor for NPP with various types of reactors (as of end of 1991)

- mean arithmetic ICUF
- mean ICUF weighted for capacity

These indicators can be evaluated against a worldwide background using diagrams (1) and (2). The foreign data presented in them are based on late March of 1991, from March 1992 for annual indicators, and from the time of connection to the power network for cumulative indicators. This slight divergence (for nuclear power plants with RBMK data are given for 1991) is not significant.

The diagrams illustrate a significant increase in mean values of ICUF for nuclear power plants with RBMK reactors over ICUF of foreign nuclear power plants. With respect to cumulative ICUF they are approached only by nuclear power plants with heavy-water channel-type reactors. It should be noted that the diagrams give mean values for all nuclear power plants with RBMK reactors. As one can see from Table 3, for nuclear power plants with RBMK-100 reactors these indicators are significantly better than for nuclear power plants with RBMK-1500 reactors, and correspondingly for the system as a whole. It may also be observed that for nuclear power plants with RBMK-1000 reactors located in the Russian Federation the mean values of ICUF are 2.5-4.0% (relative) higher than for the system of nuclear power plants as a whole.

On the other hand, one cannot help but notice that in spite of regular recording of ICUF, this indicator plays different roles abroad and in the former USSR.

As we know, ICUF is not only dependent on the nuclear power plant itself, but is a function of the load schedule, i.e., the demands of the energy system. However, due to the entirely different states of energy production, this factor relates more to foreign than to domestic energy production. In the United States the power capacity reserve of the system exceeds 30%, in the FRG it is on the level of 25%, and so on. Such reserves create considerable freedom in the load schedule of nuclear power plants and its basic character is dictated by economic considerations alone.

In the former USSR the power capacity reserve was 4-6%, and this has decreased still more in recent years. As we know, only the drop in industrial production is delaying an energy deficit. This dictates demands on operation of nuclear power plants and their ICUF which differ from those in other countries.

In this connection, among the data given in Table 4, the upper section of the table with ICUF of domestic power units is of the greatest interest.

The table illustrates two circumstances: consistently high values of mean ICUF of power units with RBMK and VVER-440 reactors and significantly lower (by 15-20%) mean ICUF of power units with VVER-1000 reactors.

Another operating indicator of nuclear power plants is unplanned shutdowns. Their number (total and those involving activation of emergency reactor protection systems) for power units of different types is given in

Table 5. In addition to non-serial reactors, this indicator is minimal for power units with VVER-440 reactors and slightly worse for power units with RBMK reactors. For power units with VVER-1000 reactors the average per-unit number of shutdowns was higher than for power units with RBMK:

in 1988 in 4.2 (with activation of RPS in 2.1);

in 1989 in 3.5 (with activation of RPS in 2.4);

in 1990 in 4.1 (with activation of RPS in 1.9);

in 1991 in 4.2 (with activation of RPS in 2.2).

Table 4

ICUF of nuclear power plants with RBMK as compared with ICUF of VVER and nuclear power plants of leading western countries

Type of reactor	1987	1988	1989	1990	1991
RBMK-1000	77.6	79.8	76.9	74.5 1)	75.8 1)
RBMK-1500	50.6	58.6	76.0 2)	77.8 2)	77.6 2)
VVER-440	79.2	79.4	80.5	79.6	-
VVER-1000	65.7	65.5	59.0	58.7	64.6 3)
USA (PWR+BWR)	58.2	63.5	62.0	64.6	68.0
FRG (PWR+BWR)	74.9	74.0	69.1	68.4	75.0
Japan (PWR+BWR)	77.4	70.7	70.5	71.2	72.8
England (Magnox+AGR)	53.6	55.9	53.5	51.8	54.2
France (PWR)	59.5	58.5	61.8	62.9	61.8

1) Taking into account power level of 700 mW (el.) regulated for some power units since June 1, 1990.

2) Calculated for regulated power level 1250 mW (el.). 3) For all VVER (BWR)

Table 5

Unplanned shutdowns at nuclear power plants of the former USSR

Type of reactor	1989				1990				1991			
	Total	Mean for unit	Act. of RPS	Mean for unit	Total	Mean for unit	Act. of RPS	Mean for unit	Total	Mean for unit	Act. of RPS	Mean for unit
RBMK	21	1.4	13	0.9	24	1.5	23	1.4	16	1.0	14	0.9
VVER-440	8	0.9	5	0.6	13	1.4	6	0.7	7	0.8	3	0.3
VVER-1000	79	4.9	36	2.2	97	6.1	42	2.6	68	4 2	32	2.0
Non-serial reactors	6	1.0	2	0.33	5	1.0	4	0.8	3	0.8	0	0
All NPP	114	2.5	56	1.2	139	3.0	75	1.6	94	2.0	49	1.1

Shutdowns involving activation of reactor protection systems figure more frequently in foreign reports. In 1989 the figures were: at United States nuclear power plants 2.2; France 2.0; FRG 1.0; Japan 0.35 cases per reactor/year.

It is interesting to compare these indices with domestic data averaged for four years (1988-1991).

The average number of shutdowns involving activation of reactor protection systems per one reactor/year was:

- 2.5 for power units with VVER-1000;
- 1.2 for power units with RBMK;
- 1.4 for all nuclear power plants.

One may thus conclude that with respect to mean indices for all nuclear power plants Russian nuclear power plants are at the world level, but this level is the result of the contribution of power units with VVER-440 and RBMK reactors, and when taking into account the number of power units and their capacity the general situation is dictated primarily by the latter.

The structure of causes of unplanned shutdowns of power units with RBMK and VVER reactors is shown in Table 6. As a result of the recordkeeping procedures used, indicators for nuclear power plants with VVER reactors include both VVER-1000 and VVER-440 reactors, which "blurs" the picture considerably, since the latter have significantly better indices than the former, and the structures of the causes of their shutdowns differ.

Table 6

Structure of causes of unplanned shutdowns according to type of reactor in 1991

Cause	RBMK		VVER	
	Number of shutdowns	%	Number of shutdowns	%
Personnel error	7	36.8	28	37.3
Fault of manufacturer	1	5.3	10	13.3
Fault of design and planning organizations	2	10.5	17	22.7
Combined causes	9	47.4	20	26.7
TOTAL	19	100	75	100

Nevertheless, these indices do permit one to draw certain conclusions. Firstly, in the total number of shutdowns, which for power units with VVER reactors was 3.95 higher in total and 2.63 times higher per power unit than for RBMK reactors given approximately equal percentages of shutdowns due to personnel error, the percentage of shutdowns caused by errors in manufacturing or of design organizations was 2 or more times smaller. Given the existing system of recordkeeping, these cases are unambiguous or evident with respect to cause, and were the result of the more numerous and complex equipment and more complex flow diagrams of power units with VVER reactors than of power units with RBMK reactors. At the same time, at power units with RBMK reactors the proportion of combined causes of power unit shutdowns,

or cases when the causes were interrelated and cannot be related unambiguously to any of the three preceding groups, was approximately 1.7 times larger.

4. ECONOMIC EFFECT OF OPERATION OF NUCLEAR POWER PLANTS WITH RBMK REACTORS

At the present time, and evidently for a long time to come, the tariffs on electrical energy in effect in this country, like the costs of energy carriers, do not and will not reflect their actual national economic effectiveness. In other countries, on the contrary, these indicators are quite stable and easily predicted, and are a good reflection of the effectiveness of the fuel-energy complex and the so-called "electrification effect."

According to various sources, the cost of electrical energy at nuclear power plants during the period from 1995-2005 in the United States will be 3.9-4.3 cents/kWxhr (given discount rates of 5.0% and 6.5%, respectively). It is lower in Europe: 2.74 cents/kWxhr in France; 2.9 in Belgium; 3.6 in Great Britain; 4.0 in Germany (all given a discount rate of 5.0%). Taking into account the fact that under the conditions developing in the Russian Federation actual discount rates there should be above average world rates, the cost of electrical energy at nuclear power plants in the Russian Federation counted in accordance with international methods and prices, should be on the level of 4.0 cents/kWxhr.

In connection with the aforementioned unreliability of domestic data correlating production of electrical energy and the national product, it seems advisable to use the estimates of the University of Pennsylvania (USA) based on anticipated electrical capacvity of the gross domestic product (GDP) in the United States, the former USSR and Western Europe in 1995-2005. These estimates, averaged by year, are (approximately): United States 0.89 kWxhr/dollar; former USSR 0.83 kWxhr/dollar; Western Europe 0.6 kWxhr/dollar.

An approximation of these indices may be used as the basis for calculating the economic effect of operation of nuclear power plants.

Proceeding from an ICUF of 70% (a conservative estimate), 35 year operating lives of power units with RBMK reactors, assuming replacement of fuel channels and restoration of "fuel channel/graphite lining" clearance, the total resource of power units with RBMK reactors for the Russian Federation (11 units) is 2360 bil. kWxhr, accrued production as of 01.01.92 794 bil. kWxhr, remaining resource (underproduction of electrical energy) 1570 bil. kW/hr. Including Chernobyl and Ignalinsk NPP, this indicator is 2560 bil. kWxhr. (Given the more conservative assumption of 30 year operating lives of power units, the remaining resource for nuclear power plants in the Russian Federation and all nuclear power plants with RBMK is 1230 and 2030 bil. kWxhr.)

Thus, the remaining resource of nuclear power plants with RBMK for the Russian Federation corresponds to a cost of electrical energy of over $60

billion, or a national product of approximately $1.9 trillion, or for all nuclear power plants with RBMK, over $100 bil. and $3 trillion, respectively.

It is interesting to compare these indices with the required expenditures to redesign nuclear power plants to bring their safety indicators to a level analogous to western nuclear power plants constructed at the same time. Factual economic data are now available for many aspects of this redesign, but continuous inflation makes it difficult to extrapolate them to the program as a whole.

Based on data for 1989-1990, using the conditional price increase coefficient during the period of redesign of 50, and a rate of $1 = 100 rubles, one can estimate costs for the Russian Federation to redesign nuclear power plants with RBMK reactors at approximately $1 billion, i.e., 1.5-2.0% of the cost of underproduction of electrical energy by nuclear power plants ($60 billion). While this estimate unquestionably requires refinement, it is obvious that the cost of redesigning nuclear power plants comprises a minor part of the value of their energy resource, and a still smaller part of the value of the corresponding national product. These costs may be realized through state support of the industry, by bringing deductions for modernization into conformance with current costs, and other measures (in more detail in Sec. 6).

5. REDESIGN AND MODERNIZATION OF NUCLEAR POWER PLANTS WITH RBMK REACTORS

At nuclear power plants with RBMK reactors a series of measures are being undertaken to redesign the power units to improve their reliability and safety. At the same time, work is in progress to retool the power units, including modernization of individual equipment units. Redesign and modernization is being carried out both independently and with the involvement of directly subcontracted agents of the Ministry of Atomic Energy and cooperatives.

Work is now being carried out primarily on the first phases of nuclear power plants. At Phase 1 of Leningrad NPP, in accordance with the Decree No. 105-40 of 01.28.89 of the Council of Ministers of the former USSR, a "Plan for modernization, improvement of technical level, redesign and capital repair of Leningrad NPP" is being implemented. This plan calls for measures such as: capital repair of basic and auxiliary equipment, buildings and structures, replacement of fuel channels, redesign of KMPTs [expansion not known] with replacement of RGK [expansion not known], assembly of the emergency core cooling system, replacement of down pipes, introduction of the "Skala-M" system, modernization of the control and protection system, measuring and test equipment, etc.

During the period from July 1989 through June 1990 work was conducted on Unit 1 of Leningrad NPP to effect full restoration of diametral clearances

between fuel channels and graphite blocks. The experience of this operation demonstrated that full replacement of fuel channels during one reactor shutdown may be combined with measures to update equipment and improve the technical level of the power unit. This experience was utilized during similar repairs at KNPP, Chernobyl NPP, SNPP and Ignalinsk NPP. Mass replacement of fuel channels is now in progress on Unit 2 of Leningrad NPP.

The repairs on power units with RBMK reactors to restore "fuel channel-graphite" clearances and replace reactor fuel channels are creating the prospect of using fuel channels with internal diameter of 86 mm (instead of 80 mm) and fuel assemblies with fuel elements with increased diameter to increase the fuel load and its burnout depth. Implementation of this measure would make it possible to improve the safety of power units, reject the constant presence of auxiliary absorbers in the cxore and reduce consumption of natural uranium and the fuel component of the cost of electrical energy by 20-25%.

The most significant area of nonconformance of active RBMK reactors with OPB-88 requirements is their lack of protective containments, which were not mandatory or regarded as feasible during the design of RBMK reactors.

Considering the presence in second-generation RBMK reactors of strong and dense boxes housing all large coolant system equipment, which are designed for pressure of 4 kg/cm^2, the lack of a common containment may be compensated by producing a "confinement" - a sealed envelope containing

radioactive leaks from the central reactor room and separator drum rooms. The design of such a confinement was developed by VNIPIET and LoTsPSK [expansions not known], and its implementation is assumed in the redesign of power units.

Calculations show that the probability of release of radioactive products above the permissible limits allowed in sanitary standards and rules decreases by 70 times following the redesign of the first phases of nuclear power plants with RBMK reactors, and will be approximately 2×10^{-6} 1 reactor/year, which meets world requirements for nuclear power plants of that generation.

The set of measures to redesign RBMK reactors, replace channels and repair graphite linings (in the seventeenth to twentieth year of operation), and also to replace some equipment, makes it possible to count on extending their design service life to 35 years. The economic effect of extending the operating life of power units is reflected in the indicators given in the previous section. One must only note that a number of factors will promote an increase in this economic effect: postponement of expenditures on decommissioning of the power unit, planning and exploration to select a site for the new power unit, development of a social infrastructure, etc.

With regard to extension of the operating life of power units - a tendency widespread abroad - it must be borne in mind that 30 calendar years, the formal operating life designated at the time of design of the power unit,

cannot be regarded as the time of its final shutdown. In the United States, for example, the designated service life of 1000-1300 mW (el.) power units is 40 years, while in France nuclear power plants have no rigidly defined lengths of operation.

6. FINANCING THE REDESIGN AND OPERATION OF NUCLEAR POWER PLANTS WITH RBMK REACTORS

The nuclear power industry is a capital- and science-intensive branch of industry, in which technology is in a continuous process of improvement and cycles of design and implementation are long. For this reason, any changes that affect the nuclear power industry, whether technical, technological, organizational, economic or legal, may cause serious difficulties in its functioning. This obviously relates to the changes now being experienced in the process of reorientation to a market economy. Essential conditions of this reorientation are acknowledgement of the actual condition of the industry and the creation of a special organizational and financial mechanism, including state support. When discussing the state of the industry as a whole, one must naturally keep in mind the fact that as a result of the different construction schedules and design characteristics, the technical end financial situations at different plants differ considerably (the latter is also true of energy systems), and cannot be regulated under identical rules.

This large and urgent problem greatly exceeds the framework of this work, so only a few points relating to the financing of redesign of nuclear power plants with RBMK reactors will be mentioned below.

Because of the situation that has arisen, financing for remodeling must clearly be provided from [illegible] sources and borrowed funds.

The first include: deductions for renovation, which must be revised upward by accelerating (modifying norms for) amortization and revaluing production resources; profits from nuclear power plants clear of taxes, including hard currency profits, which should be increased by reducing value-added taxes and increasing the tariff on electrical energy; and also possible resources of the Unified Fund for Decomissioning Nuclear Power Plants, etc.

Borrowed funds include: budget allocations, above all; long- and short-term credits on preferential terms; and an extrabudgetary stabilization fund.

The structure of borrowed and internal funds applied to redesign and their composition for different plants may differ. The general tendency, evidently, will be a gradual increase in the percentage of internal sources and a reduction of the percentage borrowed. In this connection, an increase in the tariff on electrical energy produced will be very important, and is an objective tendency during the period of transition to market relations, although it requires constant state regulation.

It is well known that programs for the redesign and updating of industry, including the nuclear power industry, also exist in other countries. Financing methods differ in different countries, and are distinguished primarily by the percentage of participation by state and private capital. However, the role of the former predominates in large programs.

One may assume that in the United States a program for financing the redesign of nuclear power plants such as that being considered would be resolved through the use of "tax depreciation" - by increasing the percentage of annual untaxed depreciation and applied according to an accelerated schedule (now 15 years in the United States for the nuclear power industry, 20 years for other industries), and through state subsidies. This approach shares common features with the methods of financing the redesign of nuclear power plants with RBMK mentioned above.

7. DESIGN OF A POWER UNIT WITH MKER REACTOR AND RENOVATION OF NUCLEAR POWER PLANTS WITH RBMK REACTORS

One of the most important factors hindering the development of the nuclear power industry is the public's negative attitude toward nuclear power since the accident at Chernobyl. Nevertheless, positive tendencies have been observed in this regard, and foreign, and to some extent Russian, experience demonstrate convincingly that purposeful work with the public gives significant results.

Such positive results may be obtained in overcoming the prejudice against channel-type water-graphite reactor designs, which has arisen since the Chernobyl accident. In this case, essentially only one objective, or more precisely, subjective obstacle to the further development of this design needs to be overcome.

The channel-type design, objectively speaking, has a number of advantages over the vessel-type design from the standpoint of safety (lower coolant pressure, reactivity margin and accumulation of fission products, the presence of heat accumulators in the core, the lack of a vessel and steam generators and the problems associated with them, a high level of natural coolant circulation, etc.) and of economy (a single-circuit design, fuel reloading while the reactor is in operation, etc.).

All of these advantages of channel-type reactors are realized in the design of the MKER-800 reactor [4]. Moreover, a complete transition in this reactor to natural coolant circulation has resulted in a significant decrease in the use of materials and specific cost, and, more importantly, it has simplified and provided a high degree of reliability of safety systems, thereby improving its level. All reactor equipment of the MKER is located inside a containment, which together with meeting safety requirements should result in greater public acceptance of the design.

The advantages of the design for a power unit with MKER-800 - reactivity characteristics, the total absence of valves in the system, the

use of passive natural circulation and injection pumps, the presence of a sealed containment, and so on - were marked by the jury of the international St. Petersburg competition for the best proposal for construction of safe, ecologically clean power units (18-22 May 1992, St. Petersbur, Russia).

No less important is the large amount of experience that has been acquired in operating channel-type reactors; in this regard the support of the collectives and management of nuclear power plants with reactors of this type is very characteristic and significant.

In both technicoeconomic and operational terms, the problem of developing and introducing power units with MKER reactors is closely linked to the problem of renovation of nuclear power facilities.

This problem includes two important circumstances. Firstly, the simple withdrawal of nuclear power plants from operation will inevitably create a number of social problems in connection with the population's occupations (towns around nuclear power plants have a narrow professional profile). Secondly, internal expenditures on the reactor departments of the decommissioned power unit will not exceed 10% of total investments in the production site of the nuclear power plant, and will comprise a still small proportion of the total cost of the industrial and social infrastructure.

The task of renovating nuclear power plants with RBMK through successive construction in immediate proximity of power units with MKER

reactors calls for careful analysis of the state of the industrial infrastructure of the nuclear power plants determination of the technically possible and economically feasible list of objects that may be suitable for further operation.

One possible version is as follows: the main building is cleared as far as possible (but not totally) of radioactive equipment; complete disassembly is postponed by approximately 40 years (the service life of the new power unit), until the level of radioactivity of the most "contaminated" structures and equipment has been reduced significantly. During this period the main building of the decommissioned power unit may house laboratories, workshops, simulators, warehouses, etc. The new power unit is constructed in direct proximity to the inactive unit (a variation has been proposed for the Leningrad NPP, in which five power units with MKER reactors would be located in the filled area between phases 1 and 2 of the plant), and the following are utilized fully or partially: service water system; hydrotechnical structures; open distributors with all electrical transmission systems and lines of communication; power supply systems for internals (diesel plant, storage batteries, backup power sources), external fire fighting equipment, external dosimetric equipment; auxiliary structures (nitrogen-oxygen plant, water purification plant); nuclear power plant transportation system, etc. The turbine generator building and equipment are partially or fully used, and spent fuel storage facilities are used as they become available. The existing construction and assembly base is used to build the new power unit. The entire social infrastructurec continues to function: the town with all

supply lines, transportation system, communications, and services. The population's level of employment remains the same or increases.

In the future more technically complex plans for renovation may be possible, which would call for more functional utilization of the main building of the decommissioned power unit and involve clearing of the reactor cavity.

In any case, analysis shows that the design acceptability of all power units introduced will be very important in carrying out the renovation of nuclear power plants, and the economic and social effects of such measures are very significant.

8. CONCLUSION

Many questions associated with the future functioning of nuclear power plants with RBMK reactors remained outside the scope of this work: the problem of the social protection of nuclear power plant workers, international cooperation in enhancing the safety and reliability of reactors, public opinion and means of improving it, and so on. All of these questions demand careful consideration.

The data given on the operation of nuclear power plants with RBMK reactors in the former USSR and in the Russian Federation clearly demonstrate

the significant role of these nuclear power plants in domestic electrical energy production.

The proportion of nuclear power plants involved in the production of electrical energy in the Russian Federation in 1991 was 11.46%. 55.7% of that contribution was provided by nuclear power plants with RBMK reactors (given 51.5% of capacity). For the Central and Northwestern Unified Power Systems, where the share of nuclear power plants in the production of electrical energy was the greatest, 22% and 33%, the contributions of nuclear power plants with RBMK reactors were 67% and 66%.

In comparison with nuclear power plants with VVER reactors, nuclear power plants with RBMK reactors had 36% greater energy production, given 14% greater capacity.

Given nearly equal average ten-year costs of electrical energy at nuclear power plants and thermoelectric plants (0.96 and 0.94 kopecks/kWxhr), its average cost at nuclear power plants with RBMK reactors was 15% less than at nuclear power plant with VVER reactors. Besides lower specific capital investments, this was the result of higher installed capacity utilization factors of the nuclear power plants and better operating indices.

In 1988-1991 ICUF of nuclear power plants with RBMK reactors was 22-30% higher than at nuclear power plants with VVER-1000 reactors. Moreover, they has approximately one-quarter the number of annual unplanned shutdowns, and

1.9-2.4 times fewer shutdowns involving activation of reactor protection systems. Among the causes of unplanned shutdowns, the number caused by design and planning organizations was approximately eight times less in 1991, for example.

With respect both to ICUF in 1990-1991 and to cumulative values of ICUF (from the time of connection to the network), nuclear power plants with RBMK reactors greatly surpassed foreign nuclear power plants with reactors of different types. With respect to cumulative ICUF they were approached only by heavy-water channel-type reqctors, but their average cumulative ICUF was 3-6% (relative) lower.

Measures taken to enhance the safety of RBMK reactors have completely eliminated the possible recurrence of an accident involving instantaneous-neutron runaway on the Chernobyl scenario, i.e., one involving the release of significant quantities of radioactivity. A set of measures are now being carried out to redesign and retool power units. Following the redesign of the first phases of nuclear power plants, which is the first priority, the probability of serious accicents involving the release of greater amounts of radioactive products than provided for under health standards, decreases by 70 times, and will be approximately $2x10^{-6}$ 1/reactor·year, which meets world requirements for nuclear power plants of that generation.

As of 1.01.1992 the remaining resource (underproduction of electrical energy during the operating life) for nuclear power plants with RBMK reactors

in the Russian Federation was 1570 bil. kWxhr, and 2560 bil. kWxhr including Chernobyl and Ignalina NPP. Given an anticipated cost of electrical energy produced by nuclear power plants of 4 cents/kWxhr and electrical power consumption of gross internal product 0.83 kWxhr (estimate by University of Pennsylvania, USA, for the former USSR), the remaining resource of nuclear power plants with RBMK reactors for the Russian Federation corresponds to a cost of electrical energy of over $60 bil. or a cost of gross product of approximately $1.9 trillion, and for all nuclear power plants with RBMK over $100 bil. and $3 trillion, respectively.

An estimate of expenditures on reconstruction of nuclear power plants with RBMK reactors in the Russian Federation is $1 billion, i.e., 1.5-2.0% of the cost of their underproduction of electrical energy. An analysis demonstrates that these expenditures can be realized through state support of the industry, bringing deductions for renovation into accord with current prices, and other measures.

It seems that because of the current arguments surrounding the future fate of RBMK reactors these data and the materials in this work may be useful in reaching a decision. The conclusion from the information offered is clear: power units with RBMK reactors should be utilized after redesign and updating, continuing to make their weighty contribution to our far from fortunate electrical energy industry.

LIST OF REFERENCES

1. Adamov Ye.O., Cherkashov Yu.M. Nekotoryye rezul'taty issledovaniy razvitiya avariyi na Chernobyl'skoy AES i sovremennoye sostoyaniye bezopasnosti AES s reaktorami RBMK [Some results of a study of the development of the accident at Chernobyl NPP and the current state of safety of nuclear power plants with RBMK reactors]. // International Conference. "Nuclear accidents and the future of nuclear power." France. Paris. 16-17 Sept., 1991.

2. L. Howles. Lead Factors to March 1991. // Nuclear Engineering International, 1991, V. 36. No. 445, p. 15-17.

3. Nuclear power's international competitiveness.// Atom, 1990, No. 402, p. 11.

4. Adamov Ye.O., Kuznetsov S.P., Cherkashov Yu.M., et al. Kontseptual'nyy proyekt mnogopetlevogo kipyashchego energeticheskogo reaktora povyshennoy bezopasnosti MKER-800 [A conceptual design of the MKER-800 multi-loop boiling power reactor of enhanced safety]. // Seminar "Safety of boiling-water reactors." Canada-USSR, Canada, Toronto, 14-18 May 1990.

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Information is given on the contribution of nuclear power plants with Chernobyl-type nuclear reactors (RBMK) to the production of electric energy in the former USSR in 1991 and previous years. The operating characteristics are analyzed, and it is found that there was a great increase in mean values of installed capacity utilization factors for RBMK reactors over those of foreign nuclear power plants. It was also found that for VVER-1000 reactors the average per unit number of shutdowns was higher than for RBMK reactors. Compared to VVER reactors, RBMK reactors had 26% greater energy production, and the ten year cost of electric energy for RBMK reactors was 15% less than that of VVER reactors.

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