NUCET NUCLEAR ENERGY AND TECHNOLOGY

Nuclear Energy and Technology 4(2): 111–118
DOI 10.3897/nucet.4.30663

Research Article

Power coefficient of reactivity: definition, interconnection with other coefficients of reactivity, evaluation of results of transients in power nuclear reactors*

Yury A. Kazansky[1], Ya.V. Slekenichs[2]

1 *Obninsk Institute for Nuclear Power Engineering, National Research Nuclear University "MEPhI", 1 Studgorodok, Obninsk, Kaluga reg., 249040 Russian Federation*

2 *Experimental Scientific Research and Methodology Center "Simulation Systems" (SSL) 133 Lenin st., Obninsk, Kaluga reg., 249035 Russian Federation*

Corresponding author: *Yury A. Kazansky* (kazansky@iate.obninsk.ru)

Academic editor: *Yury Korovin* ♦ **Received** 18 October 2018 ♦ **Accepted** 9 November 2018 ♦ **Published** 26 November 2018

Citation: Kazansky YA, Slekenichs YaV (2018) Power coefficient of reactivity: definition, interconnection with other coefficients of reactivity, evaluation of results of transients in power nuclear reactors. Nuclear Energy and Technology 4(2): 111–118. https://doi.org/10.3897/nucet.4.30663

Abstract

It is assumed by the authors of the present paper that with growing contribution of nuclear power in the production of electricity, nuclear power plants will be used to a higher degree in a manoeuvrable mode of operation rather than in the base-load mode. In other words, change of power from the nominal level to that of coverage of auxiliary loads will be becoming quite common and not so rare event as scheduled reactor shutdowns for fuel reloading or preventive works. There exist well-known problems in the use of nuclear reactors in the manoeuvrable operation mode, which include the task shared by all types of nuclear reactors. It is advisable to have a unified indicator weakly power-dependent and fairly easy to measure, which would make it possible to formulate the judgement about the nature of the transient processes within the entire power range and to assess the reactivity required for changing the power level by the preset value. Power reactivity coefficient (PRC) can be used as such indicator. Analysis was made of existing definitions and understanding of PRC in relevant references. It turned out that there is no generally accepted definition of the PRC. Based on the performed study, the following definition was suggested: the PRC is the ratio of the low reactivity introduced into the reactor to the power increment at the end of the transient process. It is assumed here that variation of reactivity is dependent on the energy released in nuclear fission but is not related to the changes of reactivity induced by feedback signals in the automatic reactor power control system.

Analysis of the relationship between the PRC and temperature coefficients and technological parameters associated with the steady-state control program was performed taking the above suggested definition into account. PRC calculations were performed using the simplest model of VVER-1000 type power reactor. It was found that PRC is weakly power-dependent.

The purpose of the present study is to investigate dependence of PRC on the temperature reactivity effects and on the technological parameters associated with the steady-state control program of the power unit, using the example of VVER-1000. Effects of PRC on the static and dynamic power reactor operation modes are analyzed.

* Russian text published: Izvestiya vuzov. Yadernaya Energetika (ISSN 0204-3327), 2018, n.1, pp. 63–74.

Keywords

Nuclear power plants, power reactivity coefficient, temperature reactivity coefficients, nuclear reactor dynamics

Introduction

Statics and dynamics of nuclear power reactors are mainly determined by their intrinsic feedback links reflecting the effects on the reactivity of temperature and pressure in the reactor as well as the nuclear physics properties of materials in the reactor core dependent on them.

It is accepted to characterize the extent of the effects produced by separate process parameter (PP) by the respective coefficient of reactivity (CR), most often the temperature reactivity coefficient (TCR) and pressure coefficient of reactivity (PrCR) of, for instance, reactor coolant, fuel or moderator.

Mathematically CRs are expressed in the form of partial derivative of reactivity with respect to the PP variation of which produces effect on reactivity. Physically, for instance, both TCR and PrCR mean the ratio of the variation of reactivity to the small variation of temperature or pressure causing the reactivity variation with all other factor influencing reactivity remaining constant.

Equations of reactor dynamics containing equations for intrinsic feedbacks written taking CR into consideration provide the most exhaustive description of the dynamic and static modes of power reactor operation, which is demonstrated in the fundamental studies of NPP reactors in Russia (Kuznetsov and Poplavsky 2012, Afrov et al. 2006; Cherkashov et al. 2006). The demand in maneuverable reactor operation modes where reactor power must be changing within wide range – from coverage of auxiliary power needs to the nominal reactor power output - will be growing with increasing number of NPPs. It is useful to have a universal characteristic of reactor operated in such mode using which it would be easy to estimate the reactivity required for prompt adjustment of power of the plant unit.

Use of such operational mode of nuclear reactors is complicated by a number of issues associated with process parameters and with neutron physics characteristics. One of such issues is the necessity to look for surplus durability margin of structural materials, stability of which against neutron flux and temperature decreases in the conditions of frequent variation of power level as compared to constant neutron flux density (Ovchinnikov and et al. 2012). This is especially important for fast reactors the most important performance indicator of which, namely, the fuel burnup depth, is limited by the stability of original physical and technical characteristics of fuel and structural materials under irradiation by limiting values of neutron flux (Kuznetsov and Poplavsky 2012; Ovchinnikov et al. 2012; Voevodin 2007). Besides the above, variations of power and, consequently, of temperature have effect for fast reactors on the neutron leakage. Effects of these processes on the calculations of PCR are not addressed in the present study. For thermal reactors operated in the maneuverable operational modes there exists the following special feature – slow (within hours) variation of reactivity after establishment of new power level is compensated by the operation of power controls, which does not influence the estimated values of reactivity required for transition of the reactor from one power level to another.

At the same time, practical application of TCR and PrCR, for instance, for prompt estimation of the reactivity worth required for preforming the planned maneuver of the reactor power is associated with certain difficulties often caused by the lack of timely updated information about the required process parameters. For example, reactor fuel temperature is not directly controlled by standard measuring channels which makes difficult application of fuel TCR in the calculations of thermal effects of reactivity of the reactor using fuel temperature.

PCR characterizing power effects of reactivity (PER) as the combined result of all effects of reactivity (Kazansky and Slekenichs 2012) appears to be more convenient for estimation of reactor behavior on power levels including the task of on-line calculation of the required reactivity.

Let us examine to what extent PCR can serve as such characteristic taking into consideration the features of light water reactors (VVER-1000).

In fact, knowing the reactor PCR $\alpha_w(w)$ within the whole range of power variations w and taking into account the steady-state control program (SSCP) used on the power unit, i.e. the w-dependences of temperature, coolant flow rate in the primary cooling loop and coolant pressure, the reactivity $\Delta\rho$ required for transition of reactor from w_1 to w_2 can be represented in the following form:

$$\Delta\rho = \int_{w_1}^{w_2} \alpha_w(w)dw.$$

Besides the above, $\alpha_w(w)$ can be regarded as a certain integral measure of inherent reactor safety (FBU NTCz YaRB 2015) because PCR negativity within the whole power range is the necessary condition of reactor stability (Kazansky and Slekenichs 2012).

If it happens that $\alpha_w(w)$ for the power unit for any SSCP is constant (or close to constant) then reactor steady-state is described by the simplest expression $\Delta\rho = \alpha_w(w_2 - w_1)$. If a simple analytical expression for $\alpha_w(w)$ cannot be derived then the conclusion is made that dynamics equations must be solved for determining $\Delta\rho$ according to the given

Δw using numerical methods, which, in principle, is what is done at present for that purpose.

The main purpose of the present study is the investigation of different PCR aspects and representation of simplified analytical model for forecasting reactor reactivity behavior in static operational modes.

Diversity of understanding about PCR

Often the description of reactor characteristics is limited by the generation of a table containing, among other coefficients of reactivity, the value of PCR or the power coefficient of reactivity as the self-evident concept. At the same time different and sometimes contradictory interpretations and definitions of PCR can be found in the reference sources (which, as a rule, are recommended as teaching aids). The most straightforward and widely spread is the PCR definition (Shirokov 2002; Vladimirov 1986) as the variation of reactivity caused by the single power variation. This definition appears to be acceptable enough on the intuitive level if certain additions are introduced which, presumably, are tacitly implied by the authors. It has to be added that power increment must be determined after power stabilization at the new level, i.e. after the transient caused by the perturbation is completed. There exist operations where such definition is extended with addition that "variation of reactivity is caused by a single reactor power variation with all other conditions remaining unchanged" (Usynin and Kusmartsev 1985; Khammel and Okrent 1970; Sarkisov and Puchkov 1983). If this clarification is understood literally, then the PCR will be equal to zero (Kazansky and Slekenichs 2012). The above formulated definition is accompanied in a number of publications by additions such as "with coolant flow rate being constant" (Ovchinnikov and Semenov 1988), or "under the condition of constant water temperature" (Seleznev 2013), or "with constant coolant temperature at the reactor core inlet" (Nier et al. 1990), or "under the condition of constancy of coolant heating and inlet coolant temperature" (FGUP 2004). Two definitions of PCR at constant coolant temperature at the reactor core inlet and PCR at constant coolant temperature in the reactor core are used in the guidance document (FGUP 2004) on the basis of which CR values are measured during VVER-1000 reactor start-up operations.

PCR was defined in (Kazansky and Slekenichs 2012) as follows: PCR is the ratio of reactivity introduced in the reactor to the power increment upon completion of the transient. It follows from the above that PCR must be negative by definition (this is inevitable because of the newly established steady-state conditions). It is also assumed that variations of reactivity are caused by the energy released from nuclear fissions (possible external heat sources are disregarded) while variations of reactivity induced by the automatic reactor power control system (APC) are not accounted for (Khetrik 1975).

Several methods for measurement of PCR on the operating power unit follow from the above definition: for instance, the method with automatic power control system switched off. Small reactivity is introduced in the reactor with APC switched off. Transient is initiated (power, fuel and coolant temperature, etc. are changing), after which a new power level is stabilized (PCR is assumed to be negative, the reactor is assumed to be stable). Ratio of the introduced reactivity to the variation of power is accepted as the estimated PCR value at the given power level.

Another method with APC switched on in the operational mode with maintained neutron flux power ("N" mode) consists of variation of the preset power. In such case APC will automatically change the reactor power by introducing the required reactivity. Similar to the previous case, the ratio of introduced reactivity to the variation of power is accepted as the PCR value. The value of introduced reactivity is estimated in both cases according to the known calibration characteristics of reactor controls. The method for PCR measurement by small variation of the preset electric power of the automatic control system during operation of the APC in "T" operational mode can also be suggested. As in the previous cases PCR is calculated in the form of the ratio of variation of reactivity to the value of variation of power upon completion of the transient.

Power coefficient of reactivity

Based on the suggested definition of PCR (variation of reactivity caused by the integral effect on it by the variations of fuel temperature, coolant temperature and pressure (Kazansky and Slekenichs 2012) occurring because of the variation of power and associated SCP of the plant unit) the following dependence of PCR on the PP can be written (Kazansky and Slekenichs 2012):

$$\alpha_w(w_0) = \left.\frac{d\rho}{dw}\right|_{\substack{w=w_0\\ t\to\infty}} = \sum_{i=1}^{n} \frac{d\rho}{dp_i} \left.\frac{dp_i}{dw}\right|_{\substack{w=w_0\\ t\to\infty}} = \sum_{i=1}^{n} \alpha_{pi} \left.\frac{dp_i}{dw}\right|_{\substack{w=w_0\\ t\to\infty}}, \quad (1)$$

where w_0 is the reactor power level; α_{pi} is the coefficient of reactivity for i-th process parameter p_i.

Thus, in accordance with (1) PCR is the ratio of the variation of reactivity to the small deviation of power from the initial level in the established steady-state mode causing the PCR variation.

In accordance with the above definition PCR possesses a number of attractive features:

– PCR is defined as the total derivative with respect to power which allows automatically taking into account its dependence on all PPs dependent on power and influencing reactivity in real conditions of operation of the power unit rather than in the conditions artificially created for stabilizing a number of PP;

- It is not difficult to experimentally measure PCR in the conditions of reactor operation because implementation of special measures for maintaining other PPs of the power unit is not required;
- PCR can be expressed through other CRs.

Thus, in normal operational modes on power levels from zero to nominal power coolant pressure is maintained constant and, consequently, the value of pressure effect of reactivity is insignificant compared to temperature effects of reactivity, and further discussion will be limited by us with two PPs influencing reactivity, i.e. with temperatures of fuel and coolant.

In this case Formula (1) will be as follows:

$$\alpha_w(w_0) = \alpha_f \left.\frac{dT_f}{dw}\right|_{\substack{w=w_0 \\ t\to\infty}} + \alpha_c \left.\frac{dT_c}{dw}\right|_{\substack{w=w_0 \\ t\to\infty}}, \quad (2)$$

where α_f is the fuel TCR; α_c is the coolant TCR; T_f, T_c, are the mean temperatures of fuel and coolant, respectively.

Let us find total derivatives of fuel and coolant temperatures with respect to power for Formula (2). Simple model of heat exchange in the reactor core (Fig. 1) with lumped parameters in the steady-state operation mode will be used for this purpose.

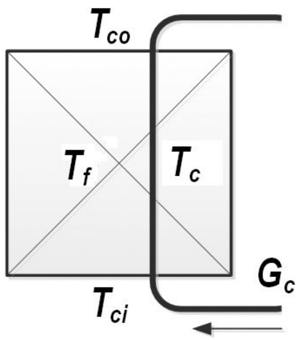

Figure1. Model of heat exchange in the reactor core: T_{ci}, T_{co} are the coolant temperatures at the reactor inlet and outlet; G_c is the coolant mass flow rate.

Relations between process parameters can be represented within the framework of the suggested model in the following form:

$$w = K_f(T_f - T_c), \quad (3)$$
$$w = G_c c_{pc}(T_{co} - T_{ci}), \quad (4)$$

where $K_f = k_f(G_c)F$ is the product of effective heat transfer coefficient k_f from fuel to coolant by the heat transfer surface area F, W/K; c_{pc} is the mean coolant heat capacity at constant pressure, J/(kg·K).

If half-sum of coolant temperatures at the reactor inlet and outlet is used as the mean coolant temperature, i.e. $T_c = (T_{co} + T_{ci})/2$, then joint solution of (3) and (4) with respect to T_c and T_f can be written under the assumption that c_{pc} = const as follows:

$$T_c = w/(G_c c_{pc}) + T_{ci} = T_c(w, G_c, T_{ci}), \quad (5)$$
$$T_f = w[K_f^{-1} + (2G_c c_{pc})^{-1}] = T_f[w, K_f(G_c), G_c, T_{ci}]. \quad (6)$$

From (5) we obtain:

$$\frac{dT_c}{dw} = \frac{\partial T_c}{\partial w} + \frac{\partial T_c}{\partial G_c}\frac{dG_c}{dw} + \frac{\partial T_c}{\partial T_{ci}}\frac{dT_{ci}}{dw}, \quad (7)$$

And from (6) we correspondingly get:

$$\frac{dT_f}{dw} = \frac{\partial T_f}{\partial w} + \frac{\partial T_f}{\partial K_f}\frac{\partial K_f}{\partial G_c}\frac{\partial G_c}{dw} + \frac{\partial T_f}{\partial G_c}\frac{dG_c}{dw} + \frac{\partial T_f}{\partial T_{ci}}\frac{dT_{ci}}{dw}. \quad (8)$$

Subsequent estimations of total derivative of fuel and coolant temperatures with respect to power are possible only with SCP of the power unit taken into account.

SCPs with constant flow rate G_c = const are applied in case of pressurized water-cooled reactors (VVER, RBMK) and, consequently, $dG_c/dw = 0$.

As it follows from (Shalman and Plyutinskiy 1979), for typical SCP power dependence of coolant temperature at the reactor inlet can be represented by the following linear function:

$$T_{ci}(w) = T_{c0} + k_{ct}w, \quad (9)$$

where T_{c0} is the initial coolant temperature, K; k_{ct} is the proportionality factor, K/W.

In particular, it follows from (5) for SSCP with constant average coolant temperature that $k_{ct} = -(2G_c c_{pc})^{-1} < 0$. Coefficient $k_{ct} = 0$ when T_{ci} = const is maintained. For the most often used SSCPs with constant steam pressure before the turbine control valves $k_{ct} > 0$ and for nuclear reactors of VVER type it is approximately equal to 0.1K/(%N_{nom}) (Seleznev 2013).

Having differentiated (5), (6) and (9) in accordance with (7) and (8) and substituting the obtained derivatives in (2) we obtain PCR in the following form:

$$\alpha_w(w) = \alpha_f(w)\left[\frac{1}{K_f(G_c)} + \frac{1}{2G_c c_{pc}} + k_{ct}\right] + \alpha_c(w)\left(\frac{1}{2G_c c_{pc}} + k_{ct}\right). \quad (10)$$

It follows from the obtained expression that PCR depends on SCP. In particular, for SCP with T_c = const any influence of TER with regard to coolant temperature is excluded in the approximation accepted in the model under examination here. In this case expression (10) acquires the following form:

$$\alpha_w(w) = \alpha_f(w)/K_f(G_c). \quad (11)$$

If T_{ci} = const is maintained the expression (10) coincides with similar expression obtained in [Kazansky and Slekenichs 2012].

It follows from expressions (10) and (11) that PCR depends on the current level of reactor power if remaining coefficients of reactivity have the same type of dependence.

Besides the above, coolant flow rate produces effect on α_w even for SCP with G_c = const, since G_c can change, for instance, due to the action of the power offload and limitation device (OLD) when one or two loops of the primary cooling circuit are cut off.

Calculation of power coefficient of reactivity

Calculation code was written in SciLab environment for estimation of PCR dependences for widely spread SCPs during operation with four, three and two cooling loops of the primary cooling circuit representing (10) for the example of VVER-1000 under typical assumptions for reactor core models with lumped parameters:

- Half-sum of coolant temperatures at the reactor inlet T_{ci} and outlet T_{co} is accepted as the average coolant temperature;
- There is no non-uniformity of coolant flow rate and energy output in the reactor core;
- Parabolic distribution of fuel temperature in the fuel pin is valid, i.e. mean fuel temperature exceeds the external temperature of the fuel rod by the value equal to two thirds of the maximum temperature differential inside the fuel rod.

Coolant heating in the reactor core is calculated as follows:

$$\Delta T_c = w / [c_{pc}(T_c, p_c) \times G_c(w)]. \quad (12)$$

Maximum fuel temperature inside the fuel pin [Kirillov P.L., 2010] is equal to:

$$T_{f\max} = T_c + q_v r_f / (2\alpha_{\text{eff}}) + q_v r_f^2 / (4\lambda f), \quad (13)$$

where q_v is the average energy output in the fuel pin, W/m^3; r_f is the fuel pin radius, m; α_{eff} is the effective heat transfer coefficient, W/(K·m^2); λ_f is the thermal conductivity coefficient of the fuel, W/(K·v); α_{eff} is calculated according to Formula (Kirillov et al. 2010):

$$\alpha_{\text{eff}} = \left(\frac{r_f / (\alpha R_f) + (r_f / \lambda_c) \ln R_f}{R_f - \delta_w} + \frac{\delta_g}{\lambda_g} \right)^{-1}, \quad (14)$$

where α is the heat transfer coefficient, W/(K·m^2); R_f is the outer fuel pin diameter, мм; δ_w is the thickness of fuel rod cladding, m; δ_g is the width of fuel rod gas gap, m; λ_c is the coolant heat transfer conductivity coefficient, W/(K·m); λ_g is the thermal conductivity coefficient of gas, W/(K·m).

Simplified formulas from (Kirillov et al. 2010) were applied for calculating heat transfer coefficient $\alpha = \text{Nu} \times \lambda_c / d_h$. Here the Nusselt number $\text{Nu} = A\text{Re}_c^{0,8}\text{Pr}_c^{0,4}$; Reynolds number $\text{Re}_c = vd_h / v_c$; Prandtl number $\text{Pr}_c = \mu_c c_{pc} / \lambda c$; parameter $A = 0{,}0165 + 0{,}02(1 - 0{,}91x^{-2})x^{0,15}$; $d_h = 2R_f(1{,}10266x^2 - 1)$ is the hydraulic diameter, m; $x = s/(2R_f)$ is the relative fuel rod pitch; s is the fuel rod pitch, m; v is the rate of coolant flow in the reactor core, m/s; μ_c, Pa×s and v_c, m^2/s are the coefficients of dynamic and kinematic viscosity of the coolant, respectively.

Linear approximation within the interval of operation al temperatures with limiting values equal to $-1{,}0 \cdot 10^{-4}$ and $-1{,}5 \cdot 10^{-4}$ K^{-1} (Sarkisov and Puchkov 1983) without accounting for the effects of changing boron concentration on the reactivity during reactor power control operations was accepted as the temperature dependence of coolant TCR $\alpha_c(T_c)$. Similar linear approximation was used for fuel TCR with limiting values equal to$-2{,}5 \cdot 10^{-4}$ and $-2{,}0 \cdot 10^{-4}$ K^{-1} (Ovchinnikov and Semenov 1988).

Calculated results

Results of calculation of PCR depending on the reactor power with fixed coolant flow rate are presented in Figs. 2 – 4 for different SCPs.

Analysis of the obtained calculated dependences demonstrates (see Figs. 2 – 4) that specific operational conditions of the power unit, including the preset SCP and operation of OLD, affect the PCR value and its dependence on the reactor power. For instance, SCP with constant average coolant temperature in the reactor weakens PER because temperature effect of coolant is practically neutralized.

Averaged PCR values within the power range of 10 – 100% N_{nom}, as well as maximum deviations of PCR from average value obtained on the basis of Figs. 2 – 4 are presented in Table 1.

It follows from the data in the Table that for constant coolant flow rate in the primary cooling circuit dependence of PCR on power is fairly weak and does not exceed 10% within the whole range of its variation, which is comparable with accuracy of the performed calculations of heat exchange in the reactor core. Therefore, PCR can be regarded in the first approximation as constant and not dependent on the reactor power.

Reduction of coolant flow rate due, for instance, to the operation of the OLD system, results in the increase of PCR absolute value which, in turn, increases self-regulation properties of the reactor and produces favorable effect on the power unit safety.

More noticeable variation of PCR (about 40%) takes place when SCP is changed, for instance, in the case of transition from SCP with constant steam throttle pressure to SCP with constant average coolant temperature in the reactor core. This fact must be taken into account in constructing combined SCPs, because change of settings of automatic control devices such as APC may be required.

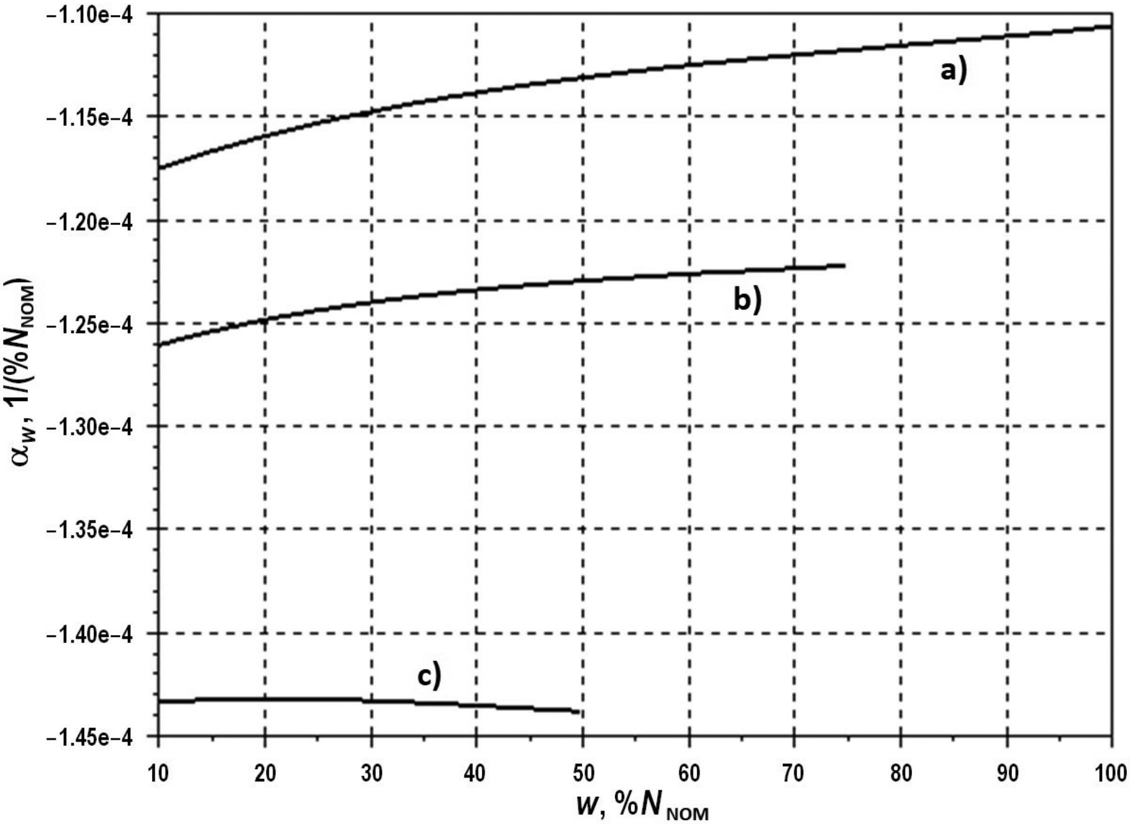

Figure 2. Calculated dependences of PCR on reactor power for the given flow rates for SCP with constant coolant temperature at the reactor core inlet: a) for nominal coolant flow rate $G_c = G_{nom}$; b) for operation with three cooling loops ($G_c = 0.75\ G_{nom}$); c) for operation with two cooling loops ($G_c = 0.5\ G$) of the primary cooling circuit.

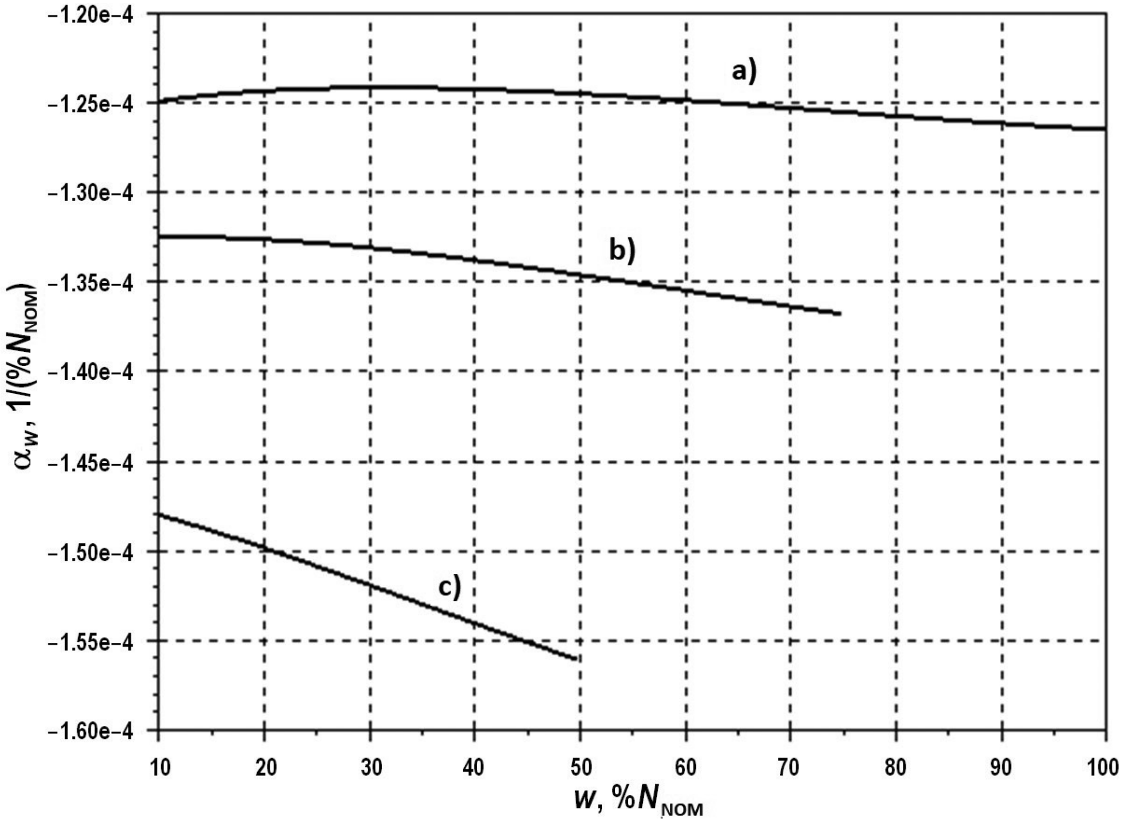

Figure 3. Calculated dependences of PCR on reactor power for the given flow rates for SCP with constant steam throttle pressure (p_2 = const): a) for nominal coolant flow rate $G_c = G_{nom}$; b) for operation with three cooling loops ($G_c = 0.75\ G_{nom}$); c) for operation with two cooling loops ($G_c = 0.5\ G_{nom}$) of the primary cooling circuit.

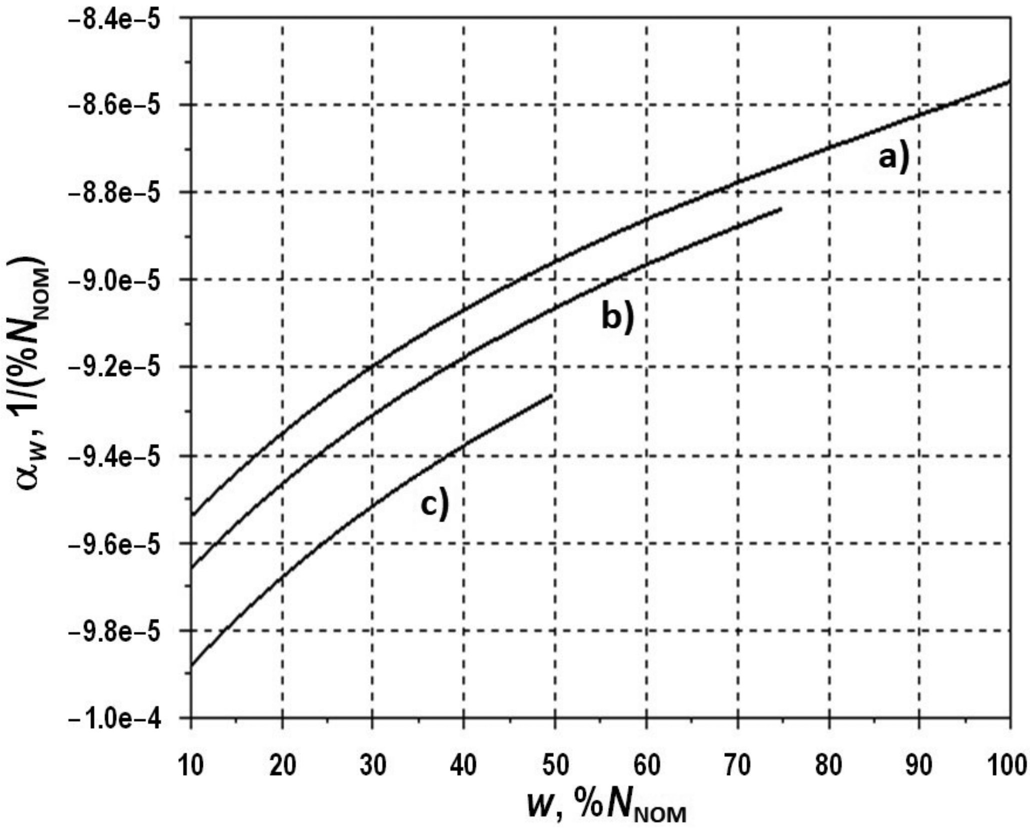

Figure 4. Calculated dependences of PCR on reactor power for the given flow rates for SCP with constant mean coolant temperature in the reactor core: a) for nominal coolant flow rate $G_c = G_{nom}$; b) for operation with three cooling loops ($G_c = 0.75\ G_{nom}$); c) for operation with two cooling loops ($G_c = 0.5\ G_{nom}$) of the primary cooling circuit.

Table 1. PCR values averaged over the power and maximum deviations from average value.

SSCP	Coolant flow rate, % $G_{c\ nom}$	Average value 1/(%N_{nom})	Maximum deviation $Da_{w\ av}$, %
	100	$-1.13\cdot10^{-4}$	3.8
T_{ci} = const	75	$-1.24\cdot10^{-4}$	2.0
	50	$-1.43\cdot10^{-4}$	0.3
	100	$-1.25\cdot10^{-4}$	1.2
p_2 = const	75	$-1.34\cdot10^{-4}$	1.9
	50	$-1.52\cdot10^{-4}$	2.7
	100	$-8.95\cdot10^{-5}$	6.6
T_c = const	75	$-9.18\cdot10^{-5}$	5.2
	50	$-9.54\cdot10^{-5}$	3.6

Conclusion

Definition of PCR in accordance with (1) as the ratio of variation of reactivity to the small deviation of power from the preset level causing the variation of reactivity in the steady-state operation mode and its expression in the form of total derivative $d\rho/dw$ allows accounting for the total impact of effects of reactivity in real operational conditions of the power unit.

As it has been already mentioned in the Introduction variation of reactivity in the transition of reactor facility from power level w_1 to power level w_2 is equal to:

$$\Delta\rho = \int_{w_1}^{w_2} \alpha_w(w)dw.$$

Straightforward and easy to use in practical calculations expression is obtained for $\Delta\rho = \alpha_w \Delta w$ for PCR weakly depending on the power typical, for instance, for reactor facilities of VVER-1000 type.

Dependence $\alpha_w(w)$ can be measured experimentally or it can be calculated using, for example, the methodology presented above.

The required TCR can be calculated using measured data obtained during reactor start-up. As applicable to VVER-1000 in accordance with (Sarkisov and Puchkov 1983) total TCR $\alpha_T = \delta\rho/\delta T_f + \delta\rho/\delta T_c$ and CR called PCR at constant coolant temperature in the reactor core are determined during power ascension according to fuel and coolant temperatures. Having the numerical values of these coefficients it is not difficult to calculate TCR values required for using Formula (10), as well as $\alpha_c = \alpha_T - \alpha_f$.

Since PCR in accordance with (1) is determined for steady-state mode of operation, then calculation of transients in the reactor on the basis of PCR does not offer special advantages as compared with initial dynamics equations. Nevertheless, the necessary conditions of reactor stability are incorporated in the dependence $\alpha_w(w)$. For achieving reactor stability, it is necessary to ensure that $\alpha_w(w) < 0$ within the whole space of technological parameters of the power unit. Only in this case the reactor will possess the feature of intrinsic self-protection, i.e. the property allowing ensuring safety on the basis of natural feedback links, processes and characteristics (Afrov et al. 2006]. Therefore, PCR $\alpha_w(w)$ determined in accordance with (1) allows to a large extent judging about the dynamics of the power nuclear reactor.

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