Reactivity effect decreases due to increasing of introduced rods quantity. It's determined that in case with six shim rods and two scram rods in the beginning of lifetime with $Gd(NO_3)_3$ concentration of 0.08 mole/l the effect is composed $(1.05 \pm 0.16)\beta_{eff}$ and satisfied to the condition of limitation of this effect by normative value no more than 1% correspondingly with the system function during the time start-up.

The using LR system as the reserve safe system allows to increase reactor sub-criticality on $0.5\beta_{eff}$ when any regulator failure and to decrease the limitations of permissible reactivity margin connected with necessarity to take into account the possibility of such failure.

The using LR system as start-up regulator allows to increase reactivity margin for fuel burnup and lifetime duration on 30%.

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ADVANCED IRRADIATION OF THE CAB-1 MATERIAL IN THE WWR-M REACTOR

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Introduction

Questions of safe exploitation of nuclear reactor structure elements are connected with radiation damage of the structural materials due to reactor radiation effects. Therefore it's important beforehand to foresee the rate and character of materials mechanical properties changes under irradiation with a glance to concrete exploitation conditions.

The WWR-M reactor operated from December 1959. During 35 years (to January 1, 1996) its energy generation reached $\simeq$ 70 GW·days what is $2 \div 4$ times more than the energy generation of same type reactors working in Russia and abroad.

The maximum fluence of neutrons with energy above 0.8 MeV on bottom of central channels which are a part of vessel is equal to $1.6 \cdot 10^{22}$ n/cm^2 (to January 1, 1996). For vessel working resources forecasting it's necessary the data of mechanical properties CAB-1 material changing at neutron fluence with the energy above 0.8 MeV $> 1.6 \cdot 10^{22}$ n/cm^2. More higher fluence was received on the control and protection system channels (CPS) worked in middle part of active core during 22 years ($1968 \div 1990$). One of them was used for samples making and measurements of CAB-1 alloys mechanical properties.

CPS channels with diameter 35 mm from the CAB-1 alloy have stainless steel insert of 200 mm height in middle part of the active core. Under drawal of the control rod stainless steel insert acts as grey screen decreasing the thermal flux and energy generation in neighbouring fuel element.

In present work it was determined by calculating experimental method thermal and fast neutron fluence at the CPS channel from which the samples for mechanical tests were prepared.

The measurement and Calculating Method

Flux densities of neutrons with energy above 0.8 MeV at CPS channels was calculated by TAY [1] and HEXA [2] codes.

Experimentally it's convenient to determine the neutron fluence by fast neutron activation of ^{93}Nb, thermal neutron activation of ^{151}Eu. But activation analysis on spectrometer with X-ray detector had been carried out by V.V.Martynov indicated that in CAB-1 and stainless steel samples from the irradiated channel have ^{152}Eu tracks and haven't ^{93m}Nb.

The activity of CAB-1 samples from CPS channel measured on γ-spectrometer of Ge-Li detector caused by ^{60}Co, on the whole, there are ^{152}Eu tracks.

^{60}Co is generated due to copper activation by fast neutrons in the reaction ^{63}Cu(n,α) ^{60}Co and due to ^{59}Co activation by thermal neutrons. According to TC CAB-1 contains $\simeq 0.01\%$ of Cu.

Effective cross-section of ^{63}Cu(n,α) ^{60}Co reaction is equal to $\sigma_{eff} = (32 \pm 3)$ mb and effective threshold $E_{eff} = 7.0$ MeV [3]. This reaction is used on the WWR-M reactor for the measurent long-term $(3 \div 5$ years) neutron fluence irradiation.

For the determination of neutron fluence in the CPS channel Cu and Co contents were measured by CAB-1 samples activation cutted out from non-irradiated part of channel. Cu content in the channel is equl to $\simeq 6 \cdot 10^{-5} \frac{g(Cu)}{g(CAB\text{-}1)}$, Co content - $(1.8 \pm 0.1) \cdot 10^{-7} \frac{g(Co)}{g(CAB\text{-}1)}$.

Taking into account the ratio of thermal to fast neutron flux on the CPS channel we obtained that CAB-1 activity by ^{60}Co dependens on the ^{59}Co activity by thermal neutrons, on the whole; the contribution of Cu activation constituted < 0.01.

Irradiated samples from CAB-1 were etched in the alkali and the acid in order to eliminate the ifluence of radioactive contaminations.

The fast neutron fluence on the CPS channel was determined from the ^{60}Co activity the measurements of two CAB-1 samples cutted from channel at distances ± 103 mm above and lower of the active core centre. In calculations it was taking into account the history of channel irradiation.

Measurement and Calculating Results

Maximum fluence of neutrons with energy above 0.8 Mev in CPS channels calculated by HEXA and TAY codes with a glance to the history of channel irradiation is equal to $2.4 \cdot 10^{22}$ n/cm^2.

Along the height of CPS P-8 channel on the boundary with fuel element (817 digital printout, March 1995) flux densities of fast and thermal neutrons were calculated and measured by activation of Au and In foils. Obtained data coincide within the limits measurements errors. Neutron flux density distribution along the CPS channel is presented in Fig. P-8 rod insertion was equal to 260 mm that corresponds to distance of ~ 80 mm between the active part of rod and middle plane of the core. In the core points at the distances ≥ 100 mm from the rod it practically not influence on the neutron flux. As far as the greatest part of lifetime the rods have insert ≤ 260 mm they not effect on neutrons fluence in the lower part CPS channels.

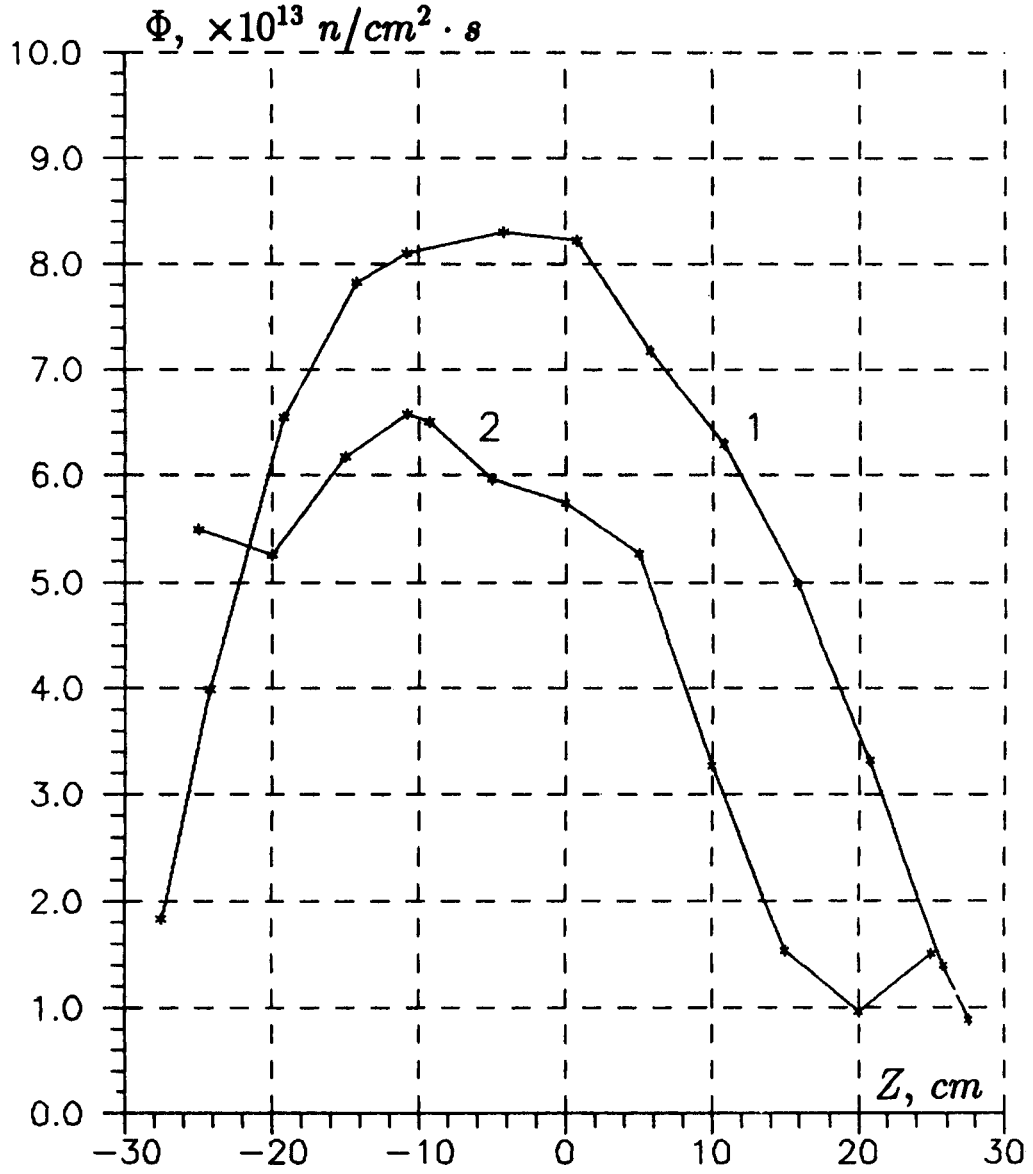

Fig. Fast (1) and thermal (2) neutron flux distribution along CPS channel

Fast neutron fluence along the lower part of the channel varies proportionally to fast neutron fluence density (Fig.).

On the sample 1 in the point −103 mm lower the centre of active core the fast neutron fluence with energy above 0.8 MeV is equal to $(2.6 \pm 0.4) \cdot 10^{22}$ n/cm^2. On the sample 2 in the point +103 mm above the centre of active core - $(2.5 \pm 0.4) \cdot 10^{22}$ n/cm^2.

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NEUTRON IRRADIATION INFLUENCE ON CAB-1 ALLOY MECHANICAL PROPERTIES

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In the present paper was investigated CAB-1 alloy mechanical properties in dependence of the fast neutron fluence by temperature from −196 to +120°C.

For the testing standard samples at tensile strength with diameter working part 3 mm irradiated in the active core of the WWR-M reactor and in DEK channel of the SM-2 reactor was used. Besides the samples making from ampoule legs and control and protection system (CPS) channel irradiated in the WWR-M reactor within 25 and 22 years accordingly were tested.

CAB-1 alloy had standard heat treatment – hardening at temperature 520°C and natural ageing at 20°C during 7 days. CAB-1 alloy chemical composition is presented in Table 1.

Fast neutron fluence on the samples in ampoules was determined by calculating experimental method by activation of companied detectors. At the samples created from legs fast neutron fluence was determined from measurements of fast neutron flux density in the legs and from irradiation history analysis. The error of fast neutron fluence measurements was 15%. The ratio of thermal neutron flux density to fast neutron flux density with energy above 0.1 MeV $\Phi_{th}/\Phi_{0.1}$ was equal to 2 in the middle plane of the active core of WWR-M reactor, to 6 – on upper level of lattice and to 10 – on lower level of lattice.

Calculated temperature of the samples exposured in the active core WWR-M reactor and leges don't exceed 65°C. Exposure temperature in the channel DEK of the SM-2 reactor was equal to $75 \div 25$°C.