Samples testings were created in the CSRI KM"Prometey", SD RDIPE and CSC SRIAR "hot" cells. Samples were tested at ephemeral tensile with velocity of gripping movement $1 \div 3$ mm/min at temperatures - 196, 20, 60, 95, 100 and 120°C.

Main research results CAB-1 alloy mechanical properties changing (yield strength $\sigma_{0.2}$, ultimate strength σ_B, uniform elongation δ_P and general elongation δ_0) depending on neutron fluence and testing temperature are given in Table 2.

At the Fig. the δ_0 dependence from the fast neutron fluence with energy above 0.1 MeV at tests temperature 20°C is given. For the comparison at the Fig. there are presented the data from the work [1] which are coincidenced with our data within error limits of measurements. With changing $F_{0.1}$ from $3.4 \cdot 10^{19}$ n/cm^2 to $5.3 \cdot 10^{21}$ n/cm^2 δ_0 decreases from 29.7% to 2.3%. At samples irradiated in the SM-2 reactor by fluence $1.2 \cdot 10^{22}$ n/cm^2 $\delta_0 = 3.8 \pm 0.8$ was received δ_0 increasing was possibly stipulated by more higher exposure temperature. At all testing samples the brittle failure was not observed.

Obtained data were used for the work resources determination WWR-M reactor vessel, It's necessary CAB-1 alloy radiation embrittlement investigations to carry on at more higher neutron fluence (10^{22} n/cm^2 and above) with enlistment statistics and dynamics investigations of cutting slightly samples with cracks.

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TOPAZ COLOURING CHANGE IN WWR-M REACTOR

K. A. Konoplev, S. Ju. Lasakova, S. P. Orlov, D. V. Tchmshkyan, G. Ja. Vasiliev

Introduction

Radiation colouring of the precious stones [1] is due to the formation of radiation damage and due to the change of electron structure of crystals. In nuclear reactor radiation damage is caused by crystal atoms displacement by means of fast neutrons; γ and β - radiation creates in crystals free conduction electrons and holes which are taken by crystal damage. As a result new stripes appear in absorbtion spectrum and crystal colouring changes.

The dependence of topaz colouring change effect from obtained radiation doze necessary for predicting radiation colouring effect was investigated in the present paper.

Radiation conditions for topaz irradiation necessary for defining optimum conditions of topaz radiation colouring in WWR-M reactor was also investigated.

Fast and thermal neutrons fluences were measured by activation method [2]. Thermal and fast neutrons flux dencities were calculated by MCU code [3], and damage doze in N_{dpa} units was calculated by TAY code [4].

Topaz Colouring Effect Change Determination in WWR-M Reactor

To quantitatively estimate the mineral colouring change effect it is necessary to determine the obtained radiation doze and colouring change effect.

As radiation doze fast neutrons fluences with energy above determined level are used. An absorbed doze is preferable to use as a radiation doze, e.g. atoms displacements number per medium atom N_{dpa}. Table 1. shows the calculation of contribution of neutrons with energy above 0.1, 1.0 and 2.0 MeV in topaz radiation damage. The data of the Table 1 show, that the use of fast neutrons fluence with energy above 1.0 or 2.0 MeV as a radiation doze may resuet in an erroneous prediction of colouring effect.

To estimate topaz colouring change effect due to an obtained radiation doze samples of flat polished plates 1.09 mm and 1.1 mm thick were taken. In spectrometer SF-46 LOMO spectra of both non-irradiated and irradiated samples were obtained. Penetration coefficient within wave range of $190 \div 1100$ nm was measured. Within $610 \div 640$ nm range a wide peak is observed which corresponds to a blue colouring; peak intesity increases as an obtained radiation doze increases (Fig.1.). Colouring effect was measured as difference in penetration coefficients both in an initial and irradiated state within wave range of $610 \div 640$ nm. An average value normalized to sample's thickness was taken to be an index of blue topaz colouring intensity.

Fig.2 shows the dependence of colouring change effect on radiation doze.

Radiation Conditions of Topaz Irradiation in WWR-M Reactor

Topaz chemical composition corresponds to $Al_2[SiO_4](F,OH)_2$ formula. As admixtures K, Na, Ca, Mg, Fe, Cr, Ti, V, Ge are observed [5].

Activation analysis showed the presence of Ta, Sc and Cs admixtures. Measurements showed that topaz when irradiated by thermal neutron fluence of $\simeq 3.4 \cdot 10^{16}$ n/cm^2 and $20 \div 40$ days later has radiation activity of $\simeq 65$ Bq/g which is primarily determined by Ta and Sc radiation activity. Permissible activity should not exceed the value of 74 Bq/g [6]. Therefore the maximum thermal neutron fluence amounts to $4 \cdot 10^{16}$ n/cm^2.

To convert a white topaz into a blue one it is necessary to attain $\Delta T \sim 20 \div 30\%$ which corresponds to radiation doze of $(1 \div 6) \cdot 10^{-3}$ dpa which corresponds, in its turn, to fast neutrons fluence for WWR-M reactor within $F_f \simeq (2 \div 8) \cdot 10^{18}$ n/cm^2 ($E \geq 1$ MeV) range. Thus, correlation between fast and thermal neutrons for optimum topaz irradiation should be $\Phi_f/\Phi_{th} \geq 10$.

Table 2 gives correlations between fast and thermal neutrons in different WWR-M reactor's areas. The table's data show that radiation topaz colouring in WWR-M reactor is impossible without special devices. To increase correlation Φ_f/Φ_{th} one may use ampoule (with irradiated minerals) screening with material which absorbs thermal neutrons very well. Cd($\sigma_c = 2500$ b) $\sim$ $0.5 \div 1$ mm thick is one of such materials. However, Cd is not a screen for resonance and fast neutrons which form thermal neutrons when slowing-down in the inner volume of the ampoule. To cut off resonance neutrons we suggest using a screen ~ 1 mm thick made of In($I_{eff} = 3100$ b). To decrease the contribution of slowing-down neutrons in the ampoule volume into topaz activation it is necessary to minimize a working volume of the ampoule.

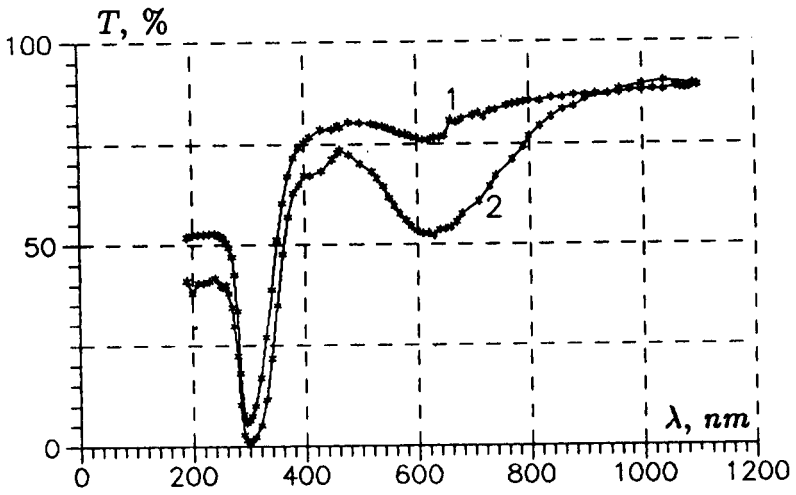

Fig.1. Spectra of non-irradiated (1) and irradiated (2) samples

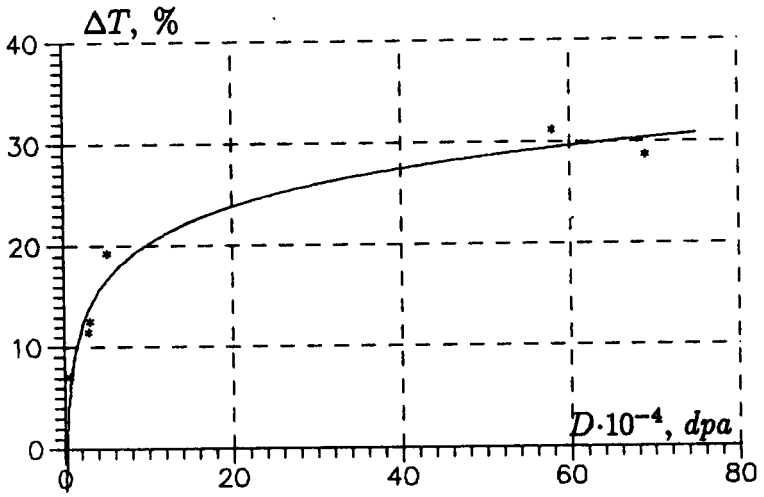

Fig.2. Dependence of colouring change effect on radiation doze

The results of experiments and calculations showed that necessary conditions for radiation topaz colouring are attained in the ampoules $\sim$ 30 mm in diameter with a screen 1mm+1mm made of Cd+In placed in the core and in the reflector's channels.

Radiation damages caused in topaz are annealed at $\geq$ 250°C. Therefore in case of irradiation at higher temperatures radiation colouring can't be obtained. Due to radiation energy release of topazes being irradiated in the reactor (Table 2), they should be cooled with water, gas or heat rejection at the expense of creating sufficient heat conductivity. In our experiments we cooled topazes by means of a weak water flow of the primary circuit.

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Table 1

Calculation of contribution of neutrons with energy above E_i MeV in topaz radiation damage in WWR-M reactor

Place of irradiation	Spectrum index		$N_{dpa} \times 10^{-22}$		
	$\frac{\Phi(E\geq 1.0)}{\Phi(E>0.1)}$	$\frac{\Phi(E\geq 2.0)}{\Phi(E>0.1)}$	$E \geq 0.1$	$E \geq 1.0$	$E \geq 2.0$
In Be reflector	0.39	0.17	7.7(100%)	4.8(62%)	2.3(30%)
Core	0.52	0.29	8.8(100%)	6.0(68%)	3.7(42%)
Behind Be reflector	0.61	0.34	9.3(100%)	6.8(73%)	4.1(44%)

Table 2

Correlations between fast and thermal neutrons in different WWR-M reactor's areas

Place of irradiation	Φ_f n/(cm^2· s · MW)	Φ_f/Φ_{th}	q [7] W/(g· MW)
Behind Be reflector	$6 \cdot 10^{10}$	0.7	0.007
Core	$1.5 \cdot 10^{13}$	3.6	0.4
In Be reflector	$7 \cdot 10^{11}$	0.1	0.04

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