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EP-450 Steel as Cladding Material for Fast Neutron Reactor Fuel Rods

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Patent № 677544 15.11.77

Material	Composition, % mass.								
	C	Si	Mn	Cr	Ni	Mo	Nb	V	B
EP-450	0.10-0.15	≤ 0.5	≤ 1.0	11.0-13.5	0.05-0.30	1.5-2.0	0.15-0.40	0.1-0.3	0.005-0.015

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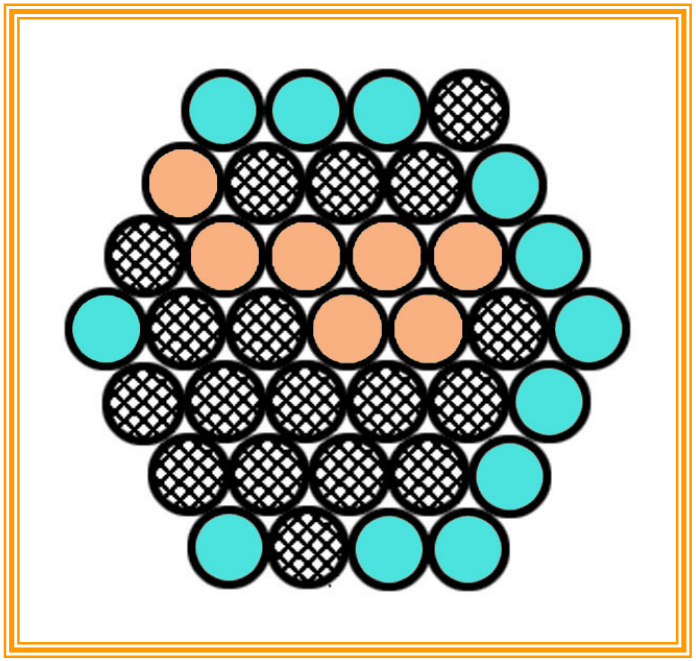
Main irradiation parameters of fuel rods with EP-450 steel claddings and pelleted oxide fuel in BOR-60 and BN-350 reactors

Reactor	FA index	UO_2 fuel pellets	Burnup %, h.a.	Dose, dpa	Test time at power, h	Linear power, W/cm	Temperature of cladding internal layer, ^0C	Test time within temperature range, h
BOR-60	A-336	90% enrichment U^{235}	12,3	49	10420	> 477 477-400	> 667 667-620	1398 8685
	A-337	- « -	13,4	41,5	13840	> 464 464-340	> 690 690-630	2970 9903
	OP-21	- « -	10,8	42	10080	> 490 490-400	725-700 700-655	1090 5780
	OP-22	- « -	10,4	40	- « -	- « -	- « -	- « -
	OP-23	- « -	10,8	42	- « -	- « -	- « -	- « -
	OP-24	- « -	10,6	41	- « -	- « -	- « -	- « -
	OP-25	**- « -**	**12,5**	**45**	**12500**	**450**	**>730 730-700**	**1640 8500**
BN-350	OP-5	32,8 % enrichment U^{235}	10,6	48	7500	536-430	690-587	-
	OP-6	33% enrichment U^{235}	11,2	60	9750	470-360	650-537	-

Chart of the OP-25 FA



- tight fuel rods;
- leaky fuel rods;
- damage fuel rods .

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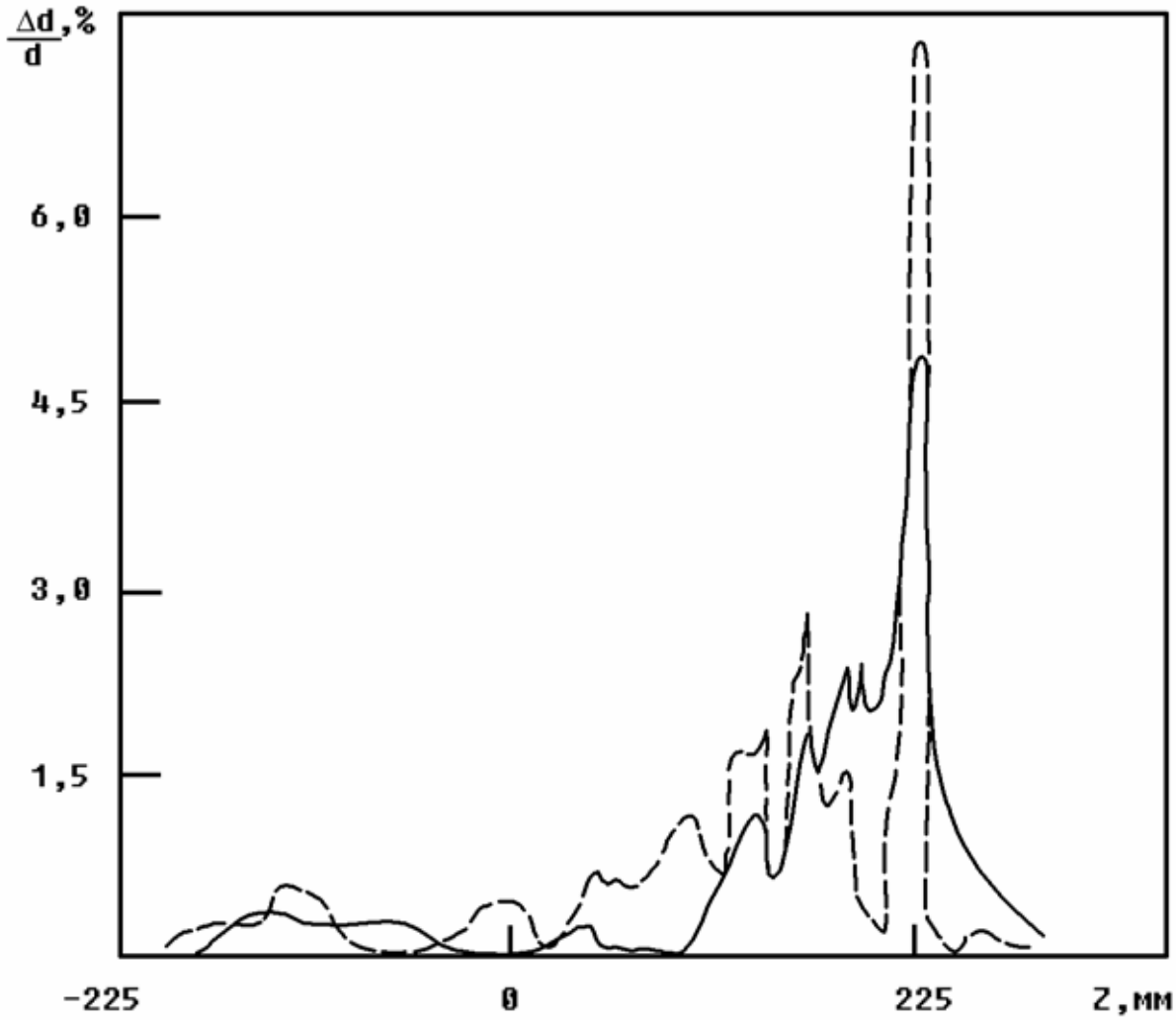
Typical diametral strain in OP-25 fuel rod



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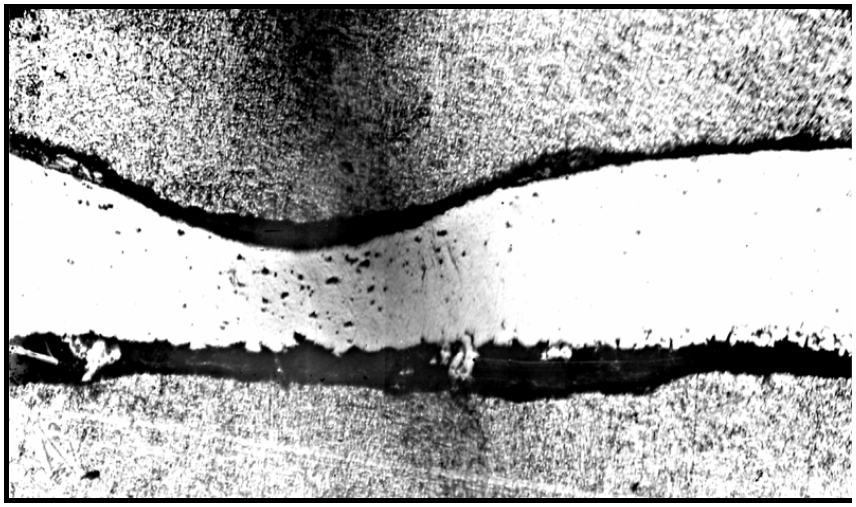
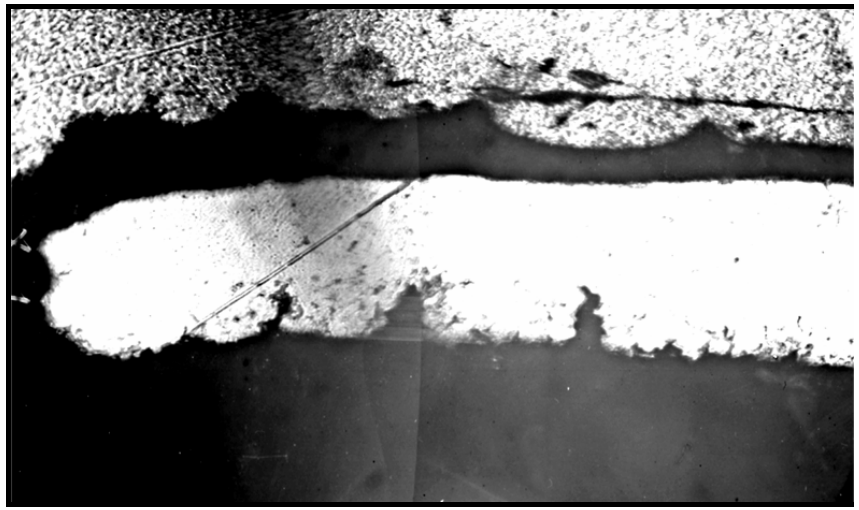
Damage fuel rods





Typical areas of local thinning damage areas and several non-through ruptures of the cladding in the upper part of the fuel rods

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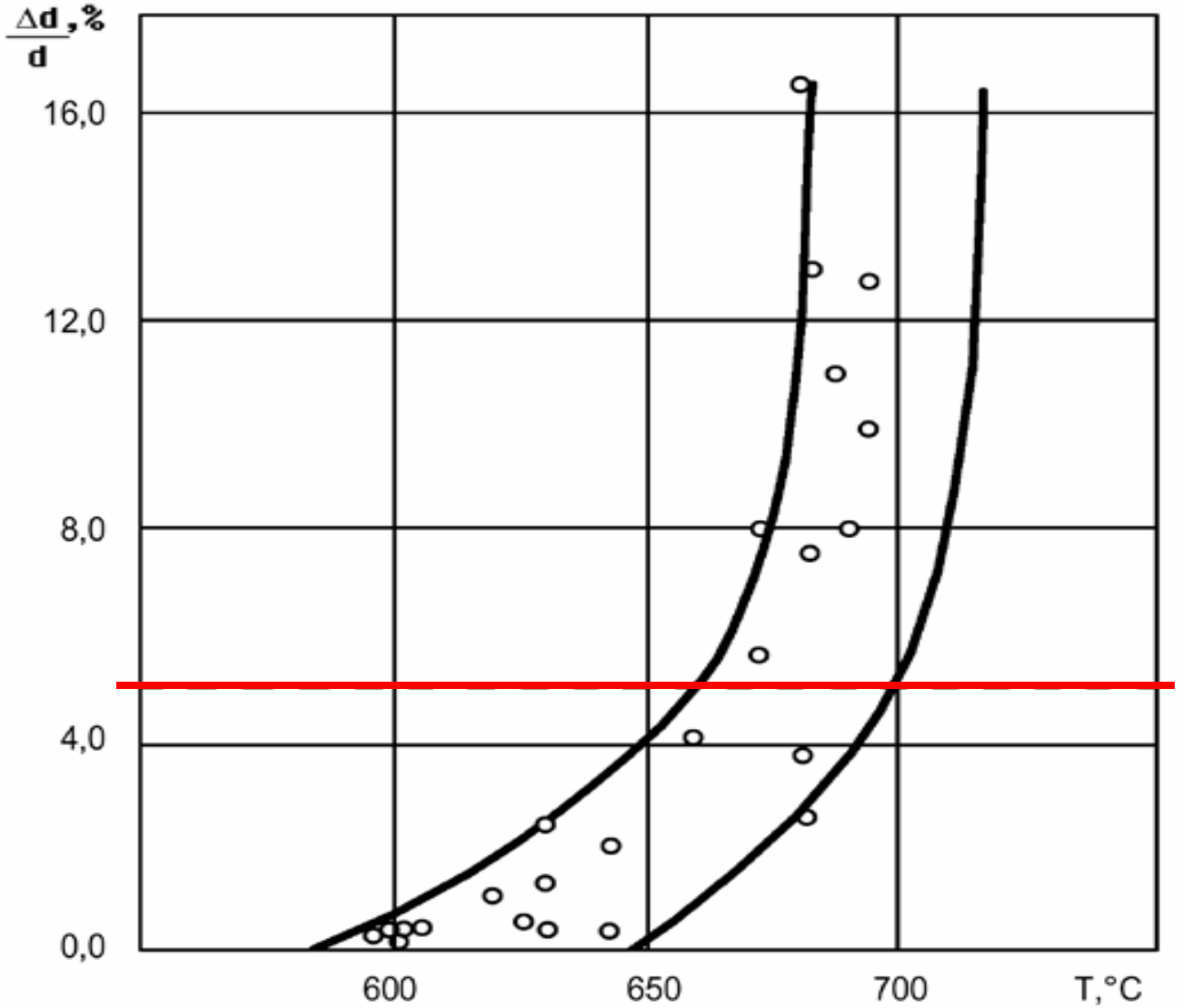
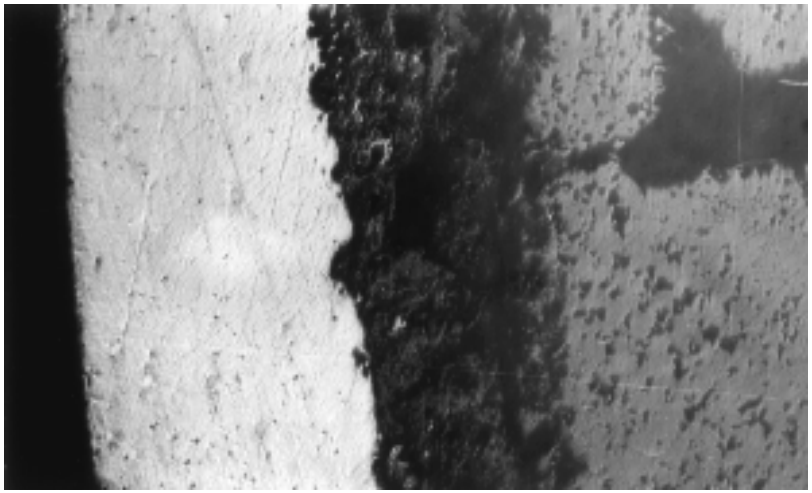
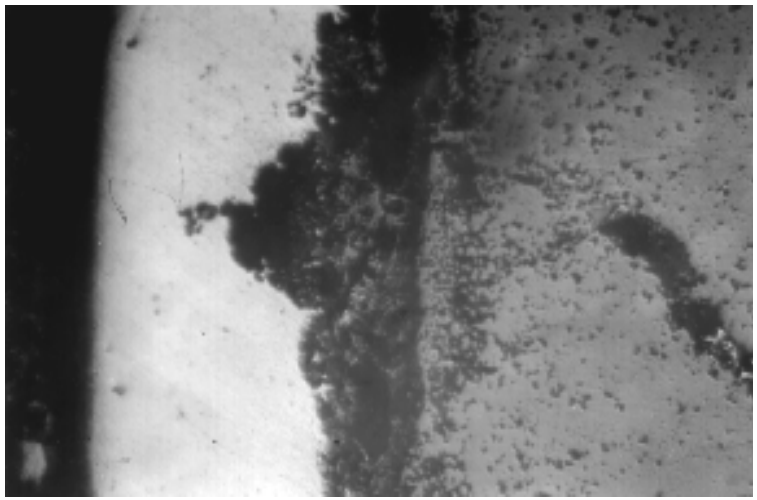


Maximum diametral strain in OP-25 fuel rods (BOR-60 reactor) vs. maximum initial irradiation temperature (--- level of maximum allowable form change)

Corrosion



a



b

Structure of cross section fragments of OP-21 fuel rods after irradiation:
a) cladding matrix corrosion;
b) cladding pitting

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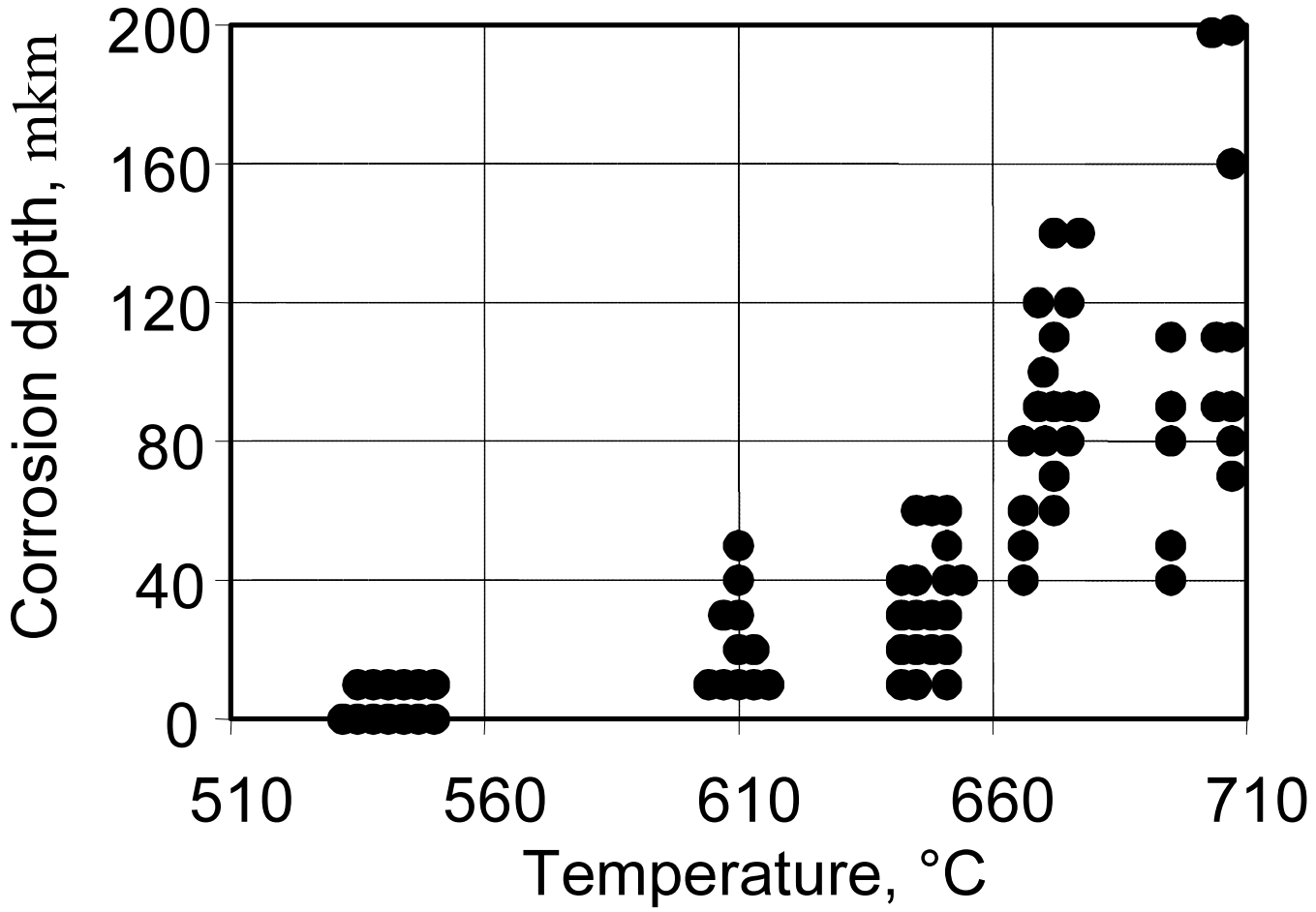
Corrosion



Temperature dependence of corrosion depth in EP-450 steel claddings at a burn-up of 10.8 % h.a.

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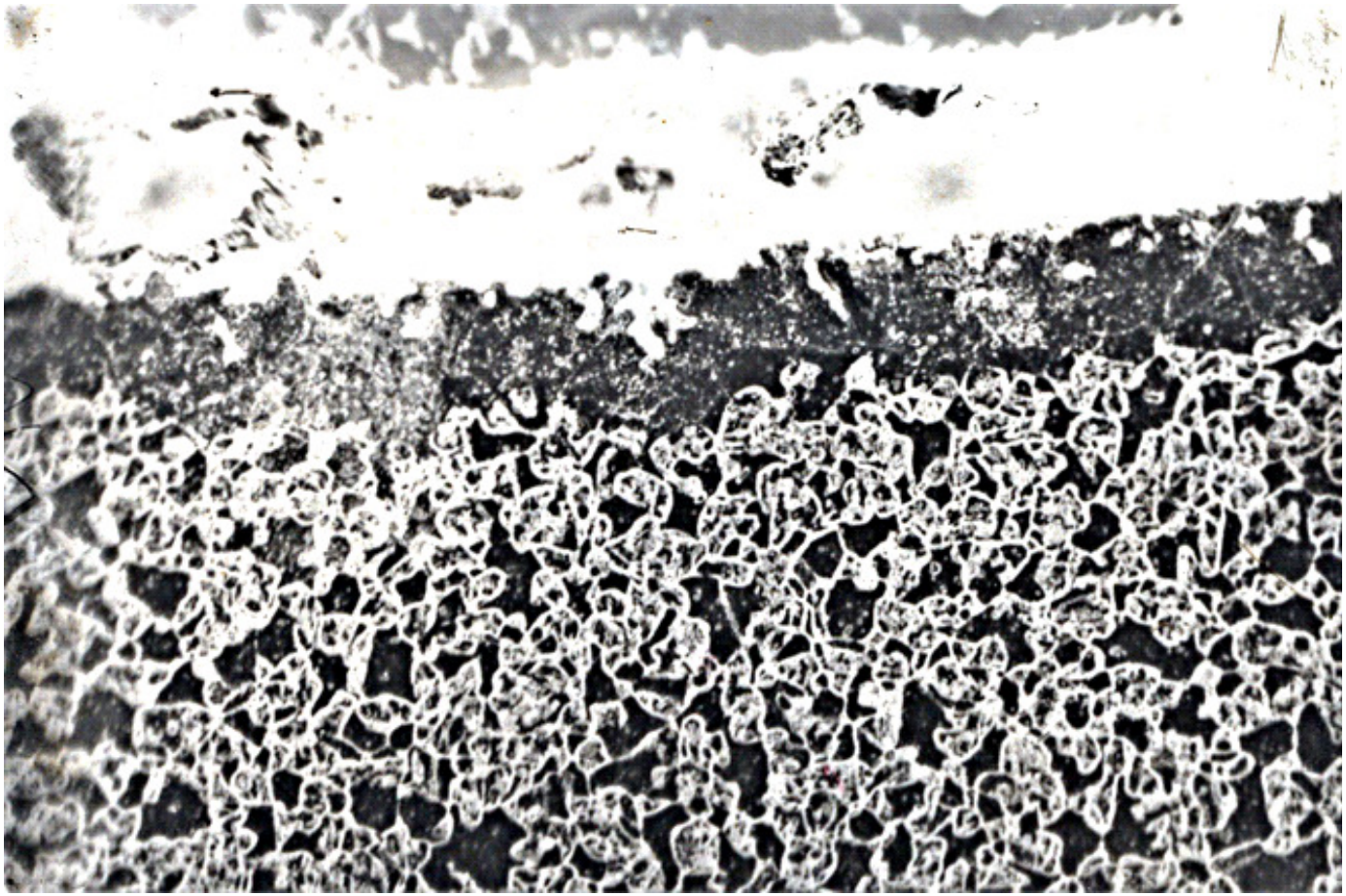
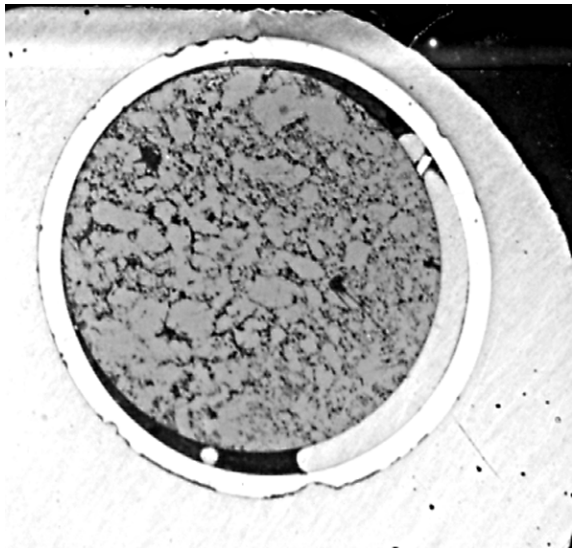
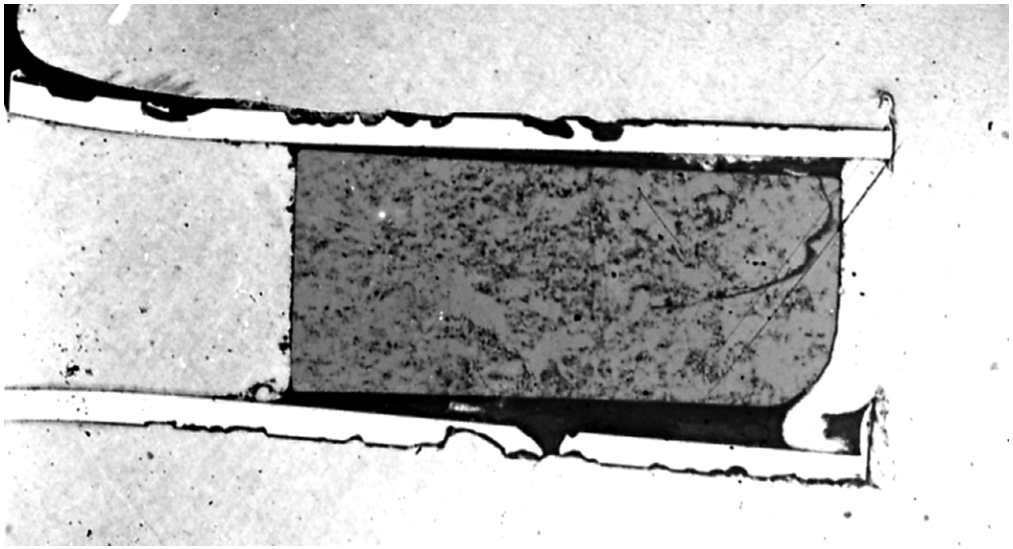
Decarburization



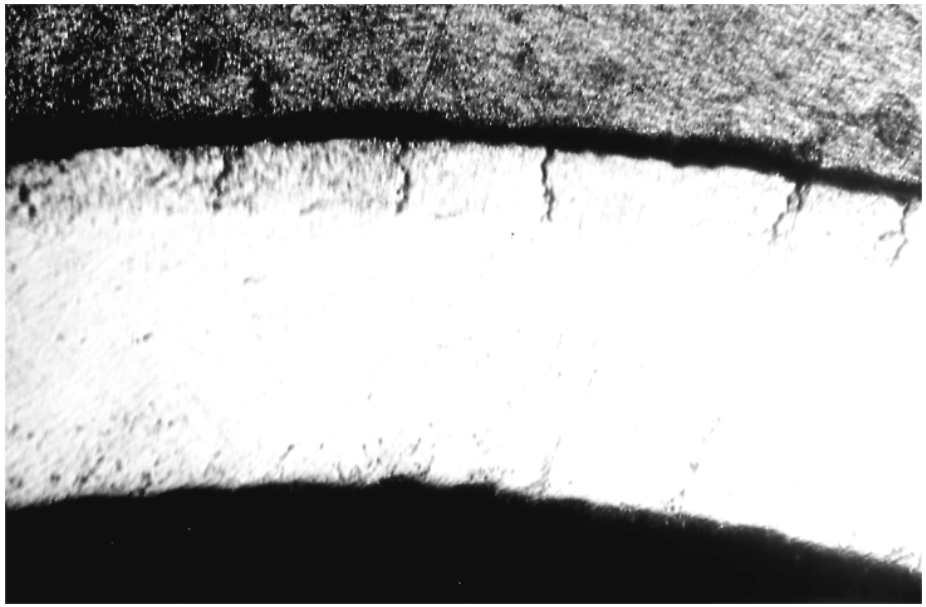
Decarburization of EP-450- steel claddings from the coolant side

Storage in cooling pool BOR-60





Storage in cooling pool BN-350



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Irradiation parameters of fuel rods with EP-450 steel claddings and vibropacked fuel

FA index	Fuel	Burnup %, h.a.	Maximum damage dose, dpa	Maximum linear power, W/cm	Maximum and minimum temperature of cladding internal layer, ^{0}C
OG-115	$(0.8U+0.2Pu)O_2$	21.0	~108	485	690 - 540
OG-116	$(0.8U+0.2Pu)O_2$	24.4	~132	476	650 - 530
OG-117	$(0.8U+0.2Pu)O_2$	27.8	~142	478	650 - 510
VS-007	UO_2	30.0	~163	352	600 - 470

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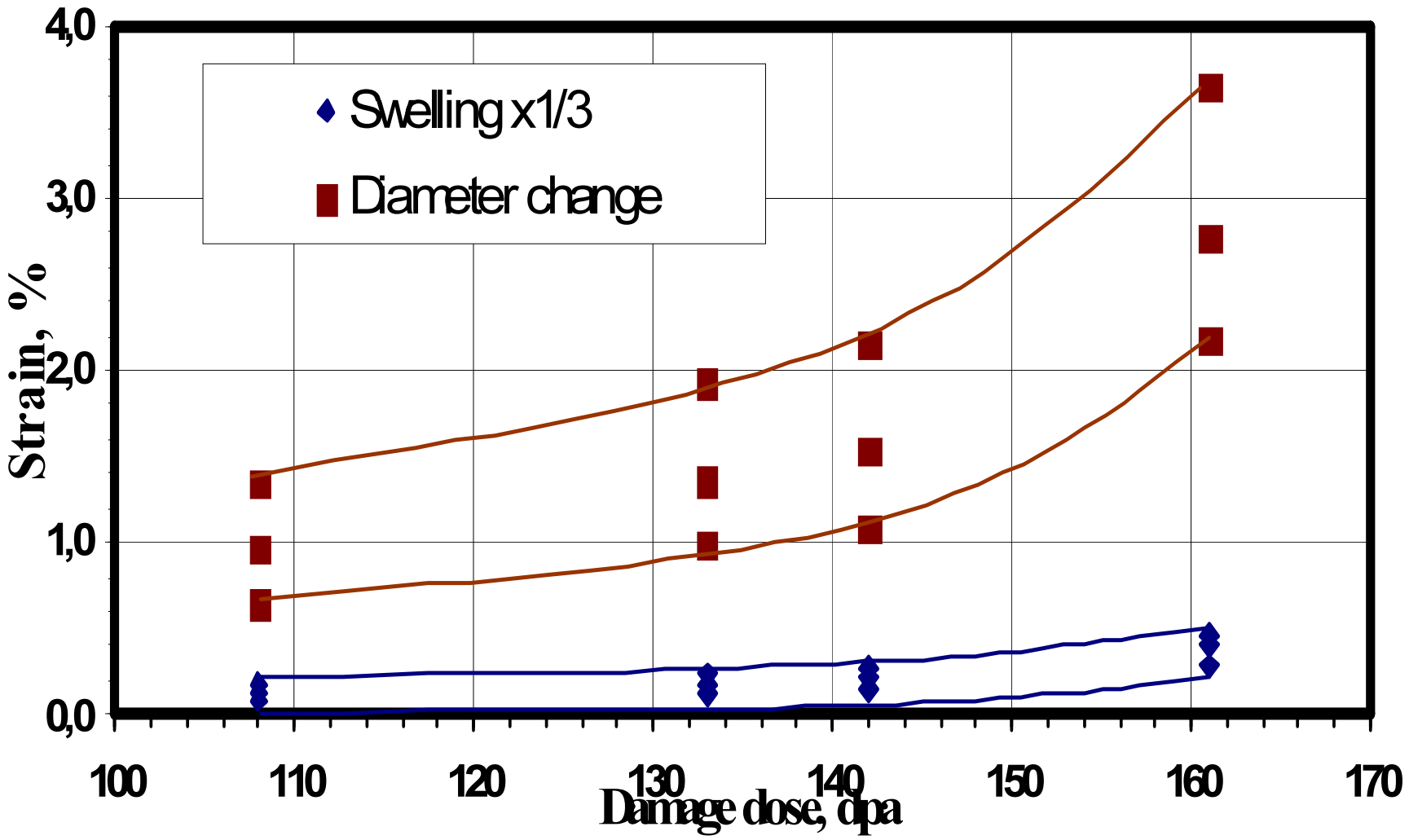
Maximum diametral strain of EP-450 steel claddings



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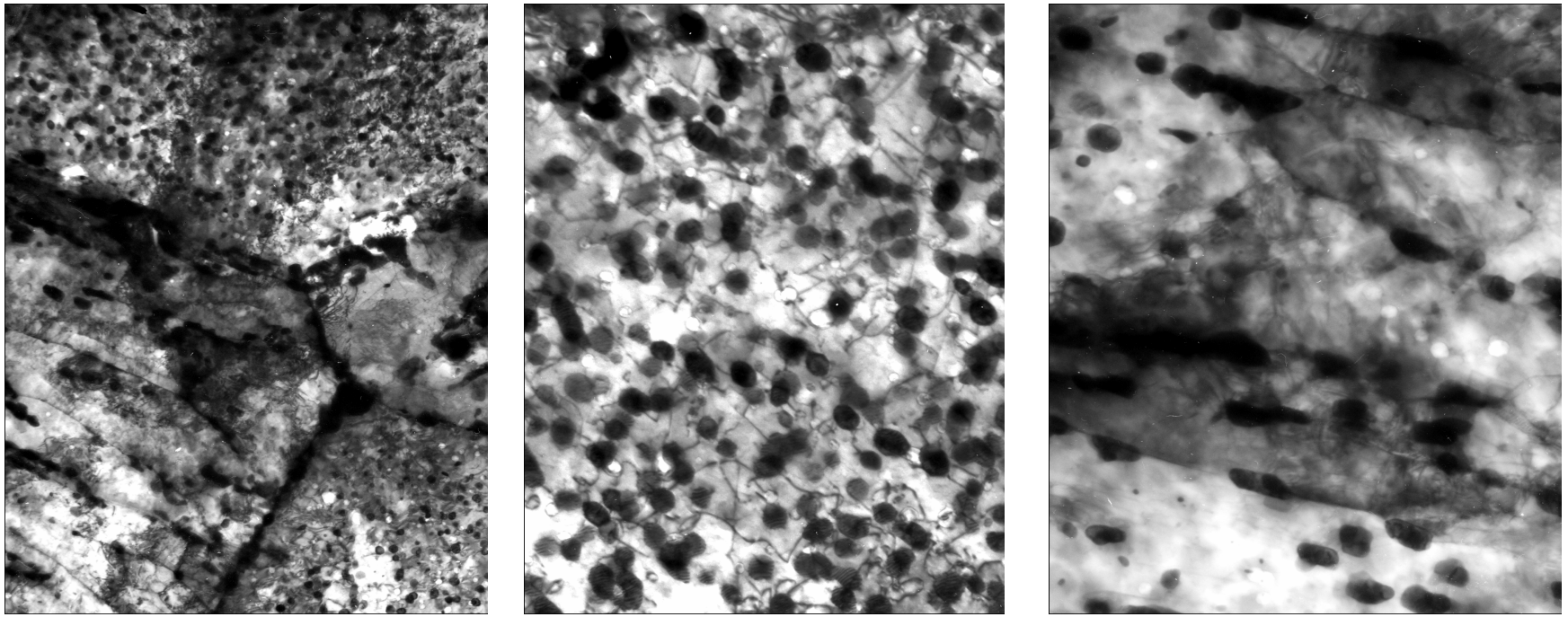
Structure of EP-450 steel



a b c

Structure of EP-450 steel as cladding material for BS-007 fuel rods irradiated in BOR-60 reactor (a – general view, x20000; b –voids, dislocation network and χ -phase precipitates in ferrite, x40000; c – voids and secondary phase precipitates in sorbite, x40000

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Conclusions

✓The EP-450 steel as a cladding material for fast reactor fuel rods retains its high resistance to radiation swelling at damage doses of up to 160 dpa.

✓The main factors hindering reliable performance of the fuel rods with EP-450 claddings are the maximum initial temperature and the level of stresses in the claddings caused by gas and fuel pressure.

✓The problems associated with heat strength and corrosion by the iodine transport reaction can be resolved by decreasing the maximum initial temperature down to 650°C.

✓Use of the EP-450 steel as a cladding material in the BN commercial reactors is impossible with the FA storage technology available now.