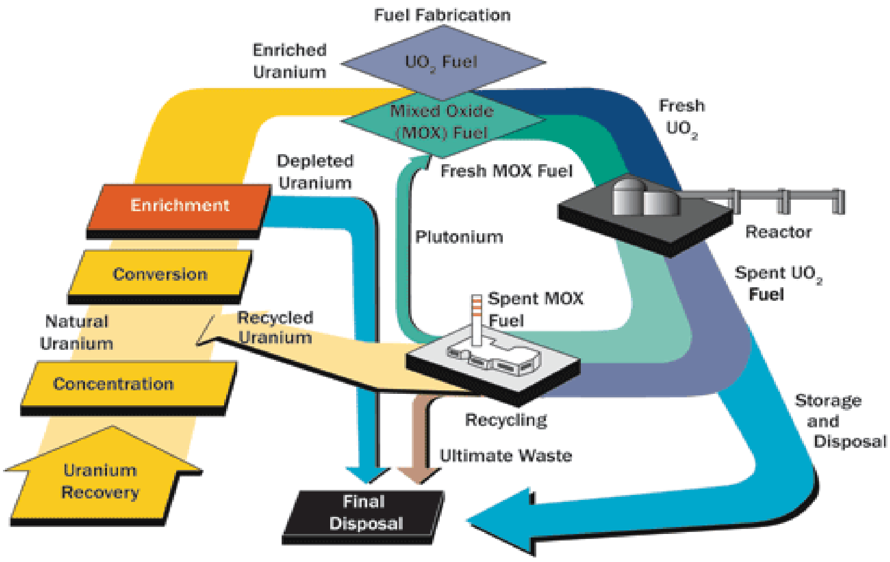
D. Mendeleev University of Chemical Technology of Russia

Troshkina I. D.

Rhenium in Nuclear Fuel Cycle

Plenary lecture at ISTR2011

Stages of the Nuclear Fuel Cycle



Source: U.S. Nuclear Regulatory Commission

RHENIUM IN THE NUCLEAR FUEL CYCLE

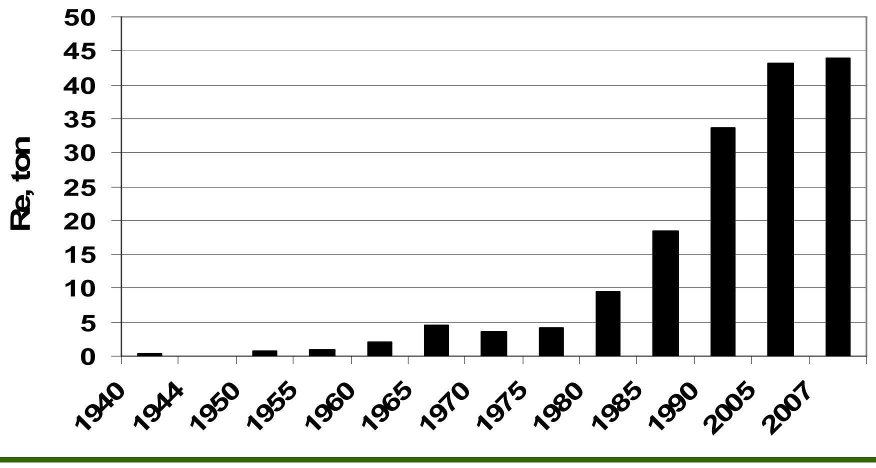
1. Associated rhenium recovery in uranium mining and hydrometallurgical processing

2. Rhenium-containing alloys - structural material of high temperature reactors

3. Rhenium as isotope production for nuclear medicine

4. Rhenium - a simulator of technetium in research

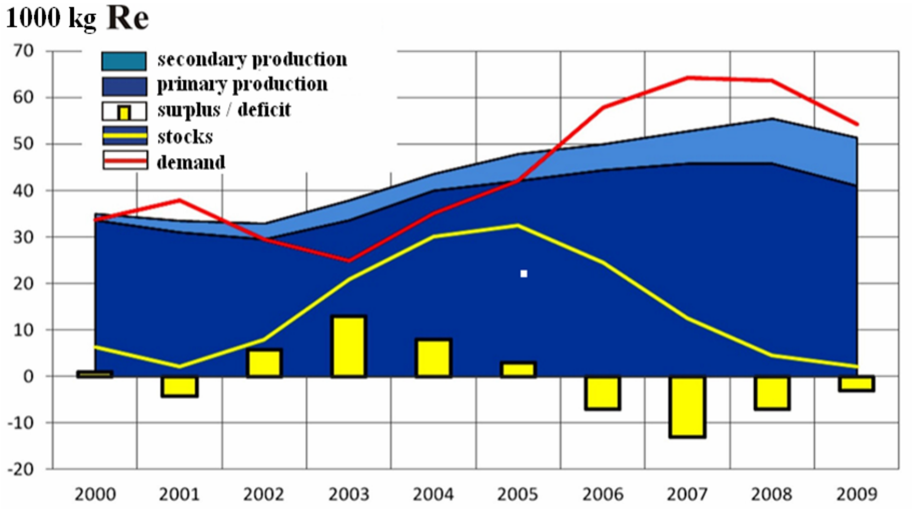
PRODUCTION OF RHENIUM



Main producing countries: Chile, USA, Poland, China, CIS (Kazakhstan, Uzbekistan, Armenia)

The dynamics of the rhenium global market

(www.roskill.com/reports/minor-and-light-metals/rhenium, 2010 г.)



The annual consumption of rhenium in 2015 will reach more than 70 t

Background

- *USA*

1969-1974, Falls City, Texas area by Susquehanna Corporation → Shattuck Chemical in Denver

- *Former USSR*

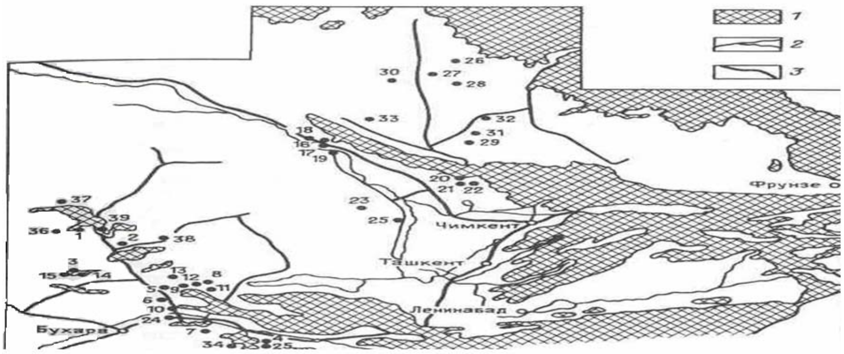
1978, Central Asia, Bukinayskaya group, underground leaching

Rhenium in the uranium ores

- ***Deposits of the sedimentary type***
- ***Stratum-infiltration exogenous deposits***

Type of the deposit	Deposit	Rhenium content, g/t
Sedimentary	**Colorado Plateau (Sun Valley)**	**0.5 –3.0**
Stratum-infiltration	**South Dakota**	**Up to 50**

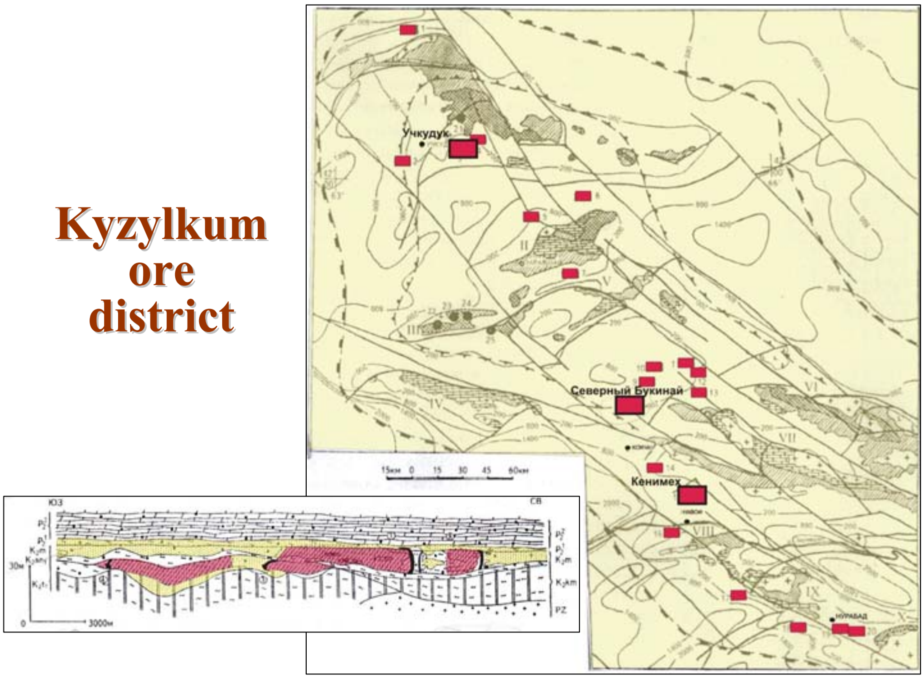
Deposits of the Prityanshanskaya Province



Deposits: 1 - Uchkuduk, 2 - Sugraly, 3 - Ore, 4 - Sabyrsay, 5 - Bukinay, 6 - Southern Bukinay, 7 - Ketmenchi, 8 - Lyavlyakan, 9 - Beshkak, 10 - North Kanimeh, 11 - Varadzhan, 12 - Terekuduk, 13 - Aland, 14 Koscheka, 15 Dzhantuar, 16 - North Karamurun, 17 - South Karamurun, 18 - Irkol, 19 Kharasan, 20 - Kyzylkol, 21 - Lunar 22 - Chayan, 23 Zarechnoye, 24 - North Mayzak 25 - Schark, 26 - Jalpak, 27 - Mynkuduk, 28 - Uvanas, 29 - Kanzhugan, 30 - Inca 31 - Moinkum, 32 - Tortkuduk, 33 - Budyonnovsk, 34 - Agron, 35 - Asarchik, 36 - Meylysay 37 - Bahaly, 38 - Aktau, 39 - Kendyktyube

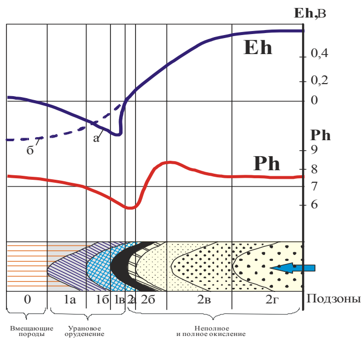
(In-Situ Leaching of Ores / N.P. Laverov *et.al.* M., 1998)

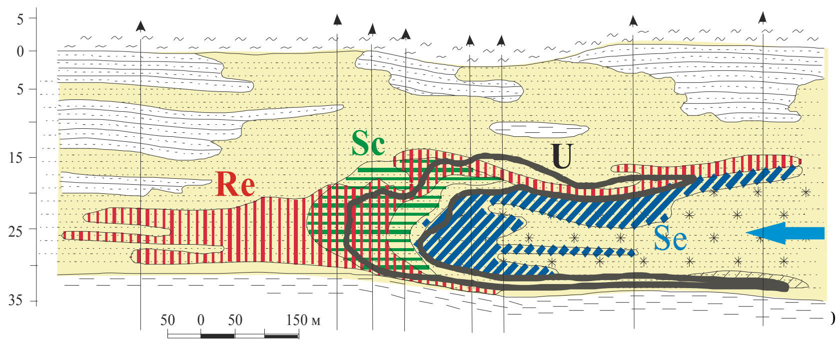
Kyzylkum ore district



Zonation Re-Sc-Se-mineralization in the contour of the uranium body

Kanimeh deposit, Uzbekistan





The rhenium content in uranium ores (the Prityanshanskaya Province)

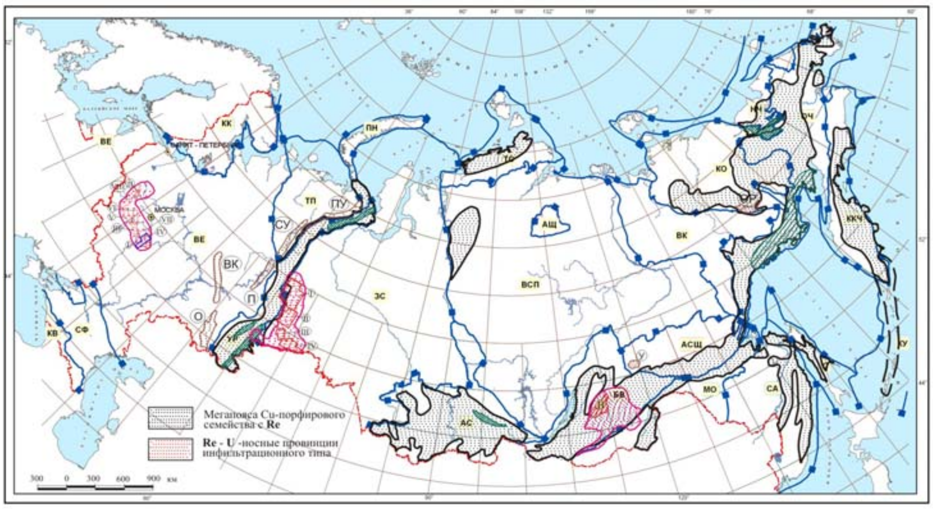
(In-Situ Leaching of Ores / N.P. Laverov *et.al.* M., 1998)

Province	The uranium content, %	The rhenium content, g/1000 kg
Central Kyzylkum	0,01-0,1	0,5-2 (to 15)
Syr-Darya	0,01-0,1	0,02-1
Chu Sarysu	0,03-0,05	0,1-0,5

Central Kyzylkum Province - North Field Bukinay, South Bukinay, Beshkak, Ketmenchi, Sabyrsay
Syr-Darya Province - North Karamurun deposit, South Karamurun
Chu Sarysu - deposits Uvanas, Kanzhugan, Mynkuduk, Moinkum

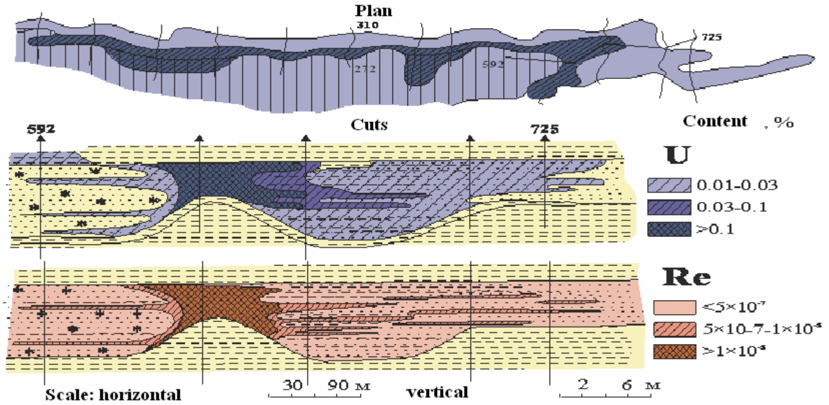
Forecasting-metallogenic map of rhenium deposits of Russia

(IMGRE, Kremenetsky A.A. and others, 2010)



Trans-Uralian Re-Mo-U ore Province

Distribution of U and Re (Dalmatovskoye deposit)
(Khalezov A.B., 2009)



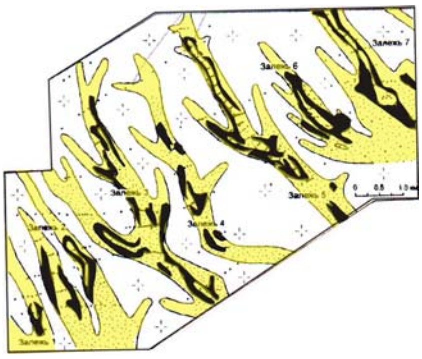
Content of rhenium, g/t

Ores	Poor	Ordinary	Rich
C_{re}	$\frac{0,05-3,12^*}{0,35}$	$\frac{0,05-4,08}{0,95}$	$\frac{0,05-19,3}{3,74}$

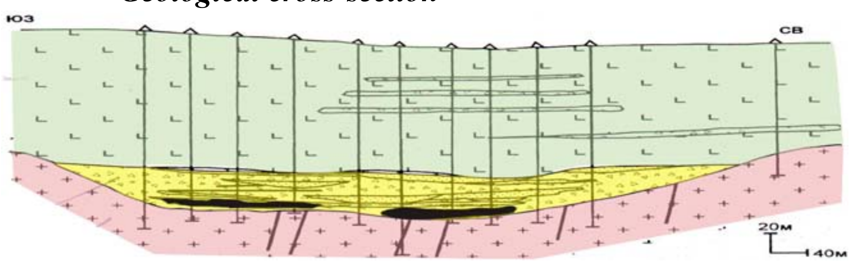
Transbaikalian Re-Mo-U province Hiagdinskoye ore deposit

(According to Sosnowski PGO)

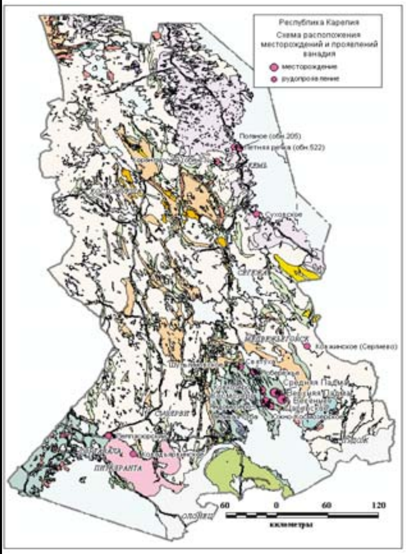
Geological Plan



Geological cross-section



V-U-Mo-precious metals-Re deposit Srednyaya Padma (Karelia, Russia)



http://www.kartravel.ru

Content of Re in ore

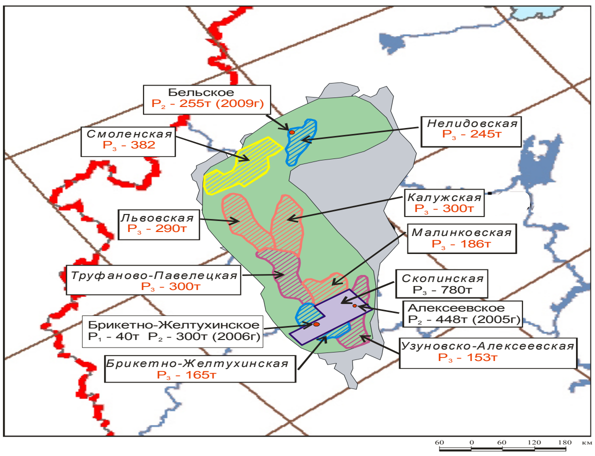
- 0.2 g/1000 kg *(Savitsky A.V., Titov V.K., Melnikov E.K., 1997)*

– **0.01-2.8 g/1000 kg** ***(Troshkina I.D., Yakushenkov N.A., Chekmarev A.M., 2003)***

Forecast resources of rhenium

(objects of infiltration type, Podmoskovnaya uranium-bearing province)

(IMGRE, Kremenetsky A.A.)

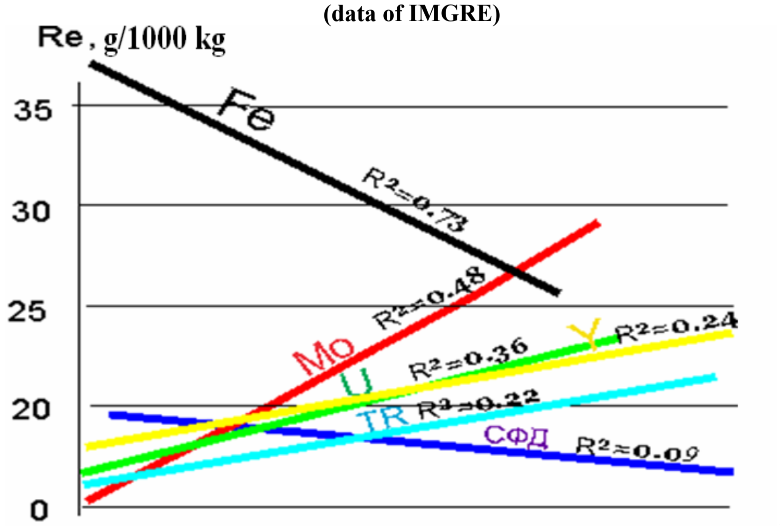


Re and related components content in the major rock types and their cement (deposit Belsky) *(data of VSEGEI)*

Rock, cement, fraction		Re	Mo	U	Th	V	Se	Y	Sc
Silts and sandstone	Gross sample	*0,86*	*4,64*	*123*	*1,9*	*95*	*1,10*	*8,99*	*1,74*
	Clay cement	*6,21*	*55,7*	*1 840*	*17,6*	*1 200*	*7,19*	*32,6*	*14,2*
	Sulfide cement	*1,03*	*27,2*	*306*	*1,93*	*121*	*7,63*	*14,7*	*2,18*
Carbonaceous alevropeschaniki	Gross sample	*1,46*	*17,5*	*14,20*	*0,71*	*14*	*0,30*	*9,33*	*1,19*
	Clay cement	*6,29*	*127*	*119*	*4,79*	*88,4*	*2,75*	*98,9*	*7,43*
	Sulfide cement	*7,7*	*237*	*625*	*65,7*	*118*	*5,93*	*403*	*45,7*
Carbonaceous silty clay and clay	Gross sample	*1,21*	*125,6*	*1 281*	*8,75*	*1 294,1*	*-*	*33,83*	*10,82*
	Carbonaceous fraction	*0,83*	*66,1*	*352*	*40,5*	*4 430*	*3,68*	*116*	*19,1*
Brown coal rocks	Gross sample	*2,35*	*22,5*	*241*	*5,24*	*3 651*	*-*	*27,6*	*27,5*
	Carbonaceous fraction	*4,14*	*80,2*	*620*	*11,1*	*9 760*	*13,1*	*66,4*	*26,3*

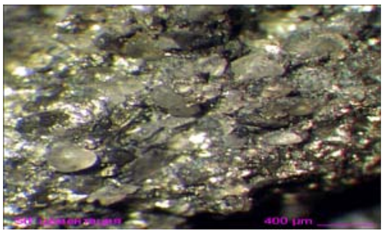
Correlation of rhenium with other metals in the ores (deposit Belsky)

(data of IMGRE)

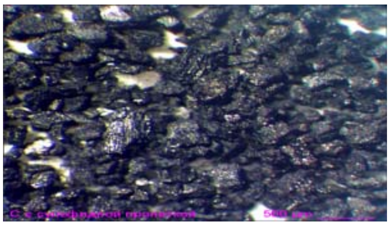


TREND OF RHENIUM ACCUMULATION IN THE ROCKS

Clay cement (up to 6.3 g/1000 kg) →
Sulphide cement (up to 7.7 g/1000 kg) →
Ultra fraction of sulfides (up to 13.0 g/1000 kg) →
Ultra-thin fraction of coal (up to 30.0 g/1000 kg)



Sulfide-carbonaceous cement



Coal with microscopic inclusions of sulfides

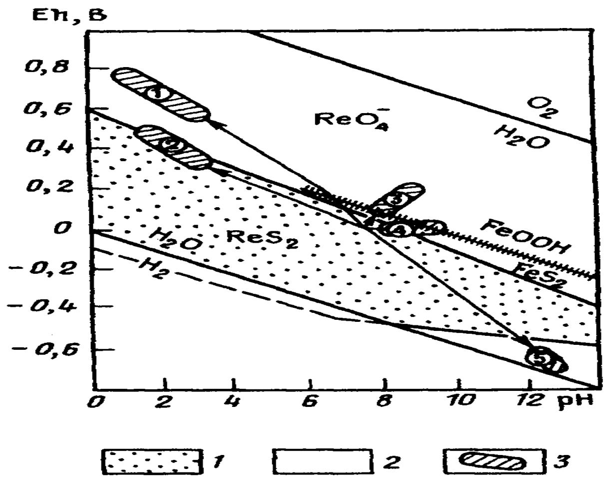
Rhenium in the ore bodies found in three forms:
oxide, sulphide and native **(data of IMGRE)**

Polymetallic ores classification in terms of productivity

(rhenium stock per unit area)

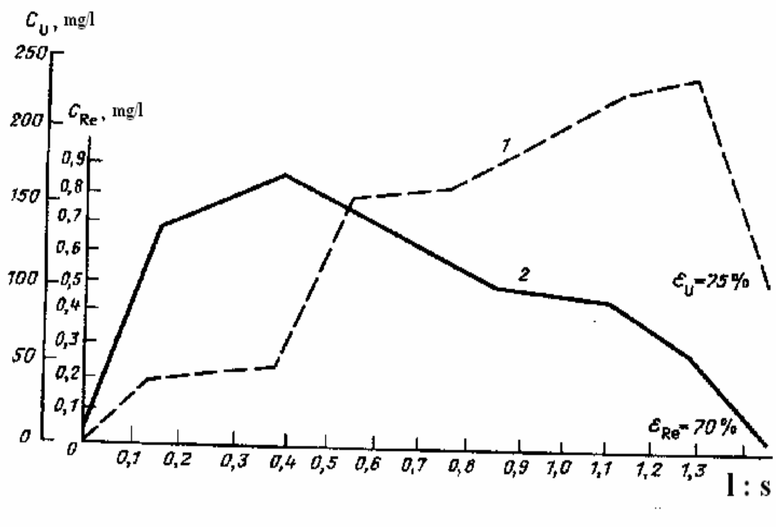
(In-Situ Leaching of Ores / N.P. Laverov *et.al.* M., 1998)

- **Very poor (to 1 g/m²)**,
- **Low-productivity (1-5 g/m²)**,
- **Ordinary (5-10 g/m²)**,
- **Highly (more 10 g/m²)**

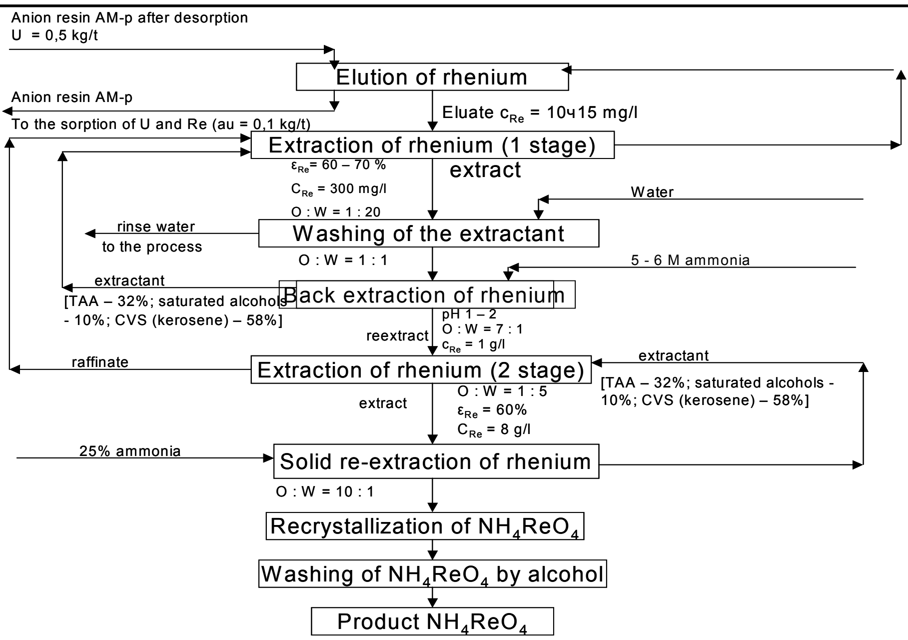


(In-Situ Leaching of Ores / N.P. Laverov *et.al.* M., 1998)

ReS_2(solid) + 4.75 O2(g) + 2.5 $H_2O \rightarrow ReO_4^-$ (liq) +2 SO_4^{2-} (liq) + 5 H^+ (liq)

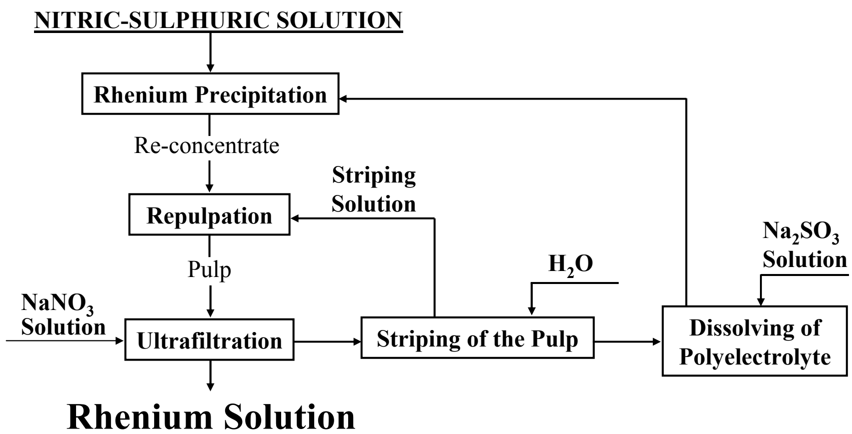


(In-Situ Leaching of Ores / N.P. Laverov *et.al.* M., 1998)



(In-Situ Leaching of Ores / N.P. Laverov *et.al.* M., 1998)

FLOW SHEET FOR RECOVERY OF RHENIUM FROM NITRIC-SULPHURIC SOLUTIONS



Rhenium deposition by polyelectrolytes from uranium-contained nitrate-sulfate eluates

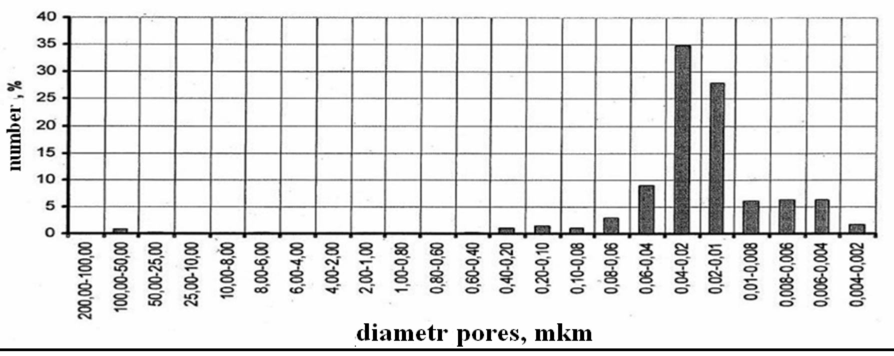
NH_4NO_3: $(NH_4)_2SO_4$ = 1:3, pH-7,2

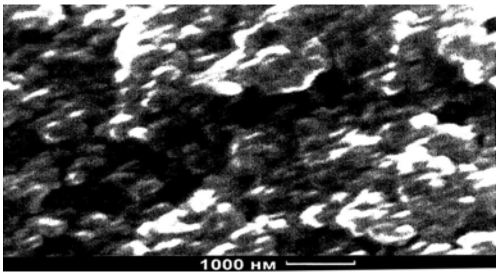
№	Type PE	Rhenium content in filtrate, mg/l /degree of, % by PE:Re (mass.)				
		4,3	21,7	43,0	130	430
1	AC-392	16,3/2,4	13,9/16,8	14,6/6,8	11,0/34,1	5,5/67,1
2	AC-412	15,0/10,2	13,6/18,6	12,2/26,9	8,4/49,7	4,8/71,3
3	ОП-1-76	-	-	13,6/18,6	-	6,1/63,5
4	ОП-3-78	16,7/0	15,8/5,4	15,0/10,2	10,5/37,1	6,0/64,1
5	АП-312	15,5/7,2	16,0/4,2	15,5/7,2	13,4/19,8	9,8/41,3
6	АП-312-2	16,8/0	14,4/13,8	15,0/10,2	12,8/23,4	10,0/40,1
7	АП-392	16,7/0	16,0/4,2	15,8/5,4	10,5/37,1	7,0/58,1
8	АП-400	16,0/4,2	14,2/15,0	13,4/19,8	10,8/35,3	5,3/68,3
9	АП-411-1	16,0/4,2	16,0/4,2	15,8/5,4	15,0/10,2	13,9/16,8

RHENIUM SORPTION FROM PRODUCTIVE SOLUTIONS OF UNDERGROUND LEACHING OF URANIUM ORES BY EXCHANGER OF NEW GENERATION (RUSSIAN FEDERATION)

(Troshkina I.D., Balanovsky N.V., Shilyaev A.V. etc. Chemical Technology, 2011)

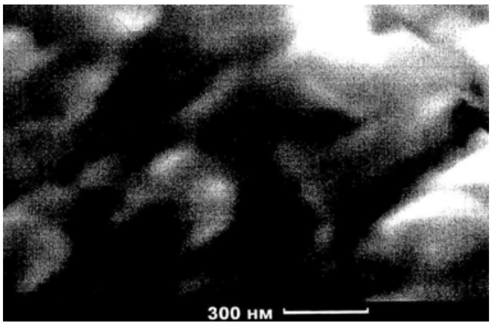
Typical pore size distribution in nanostructured ion exchangers

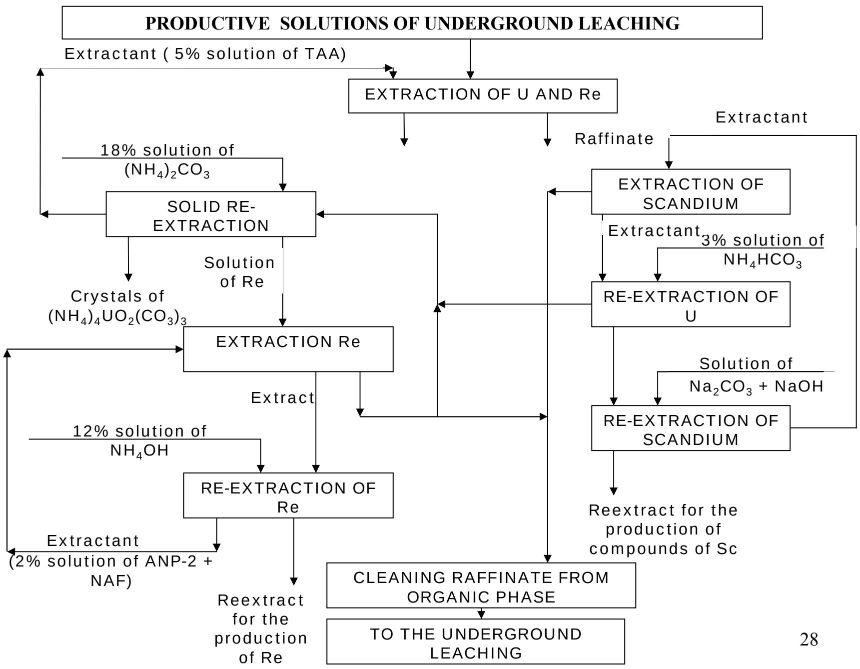




Spherical microgranules 200 - 400 nm

Predominant pore diameter 100 nm - channels between microgranules



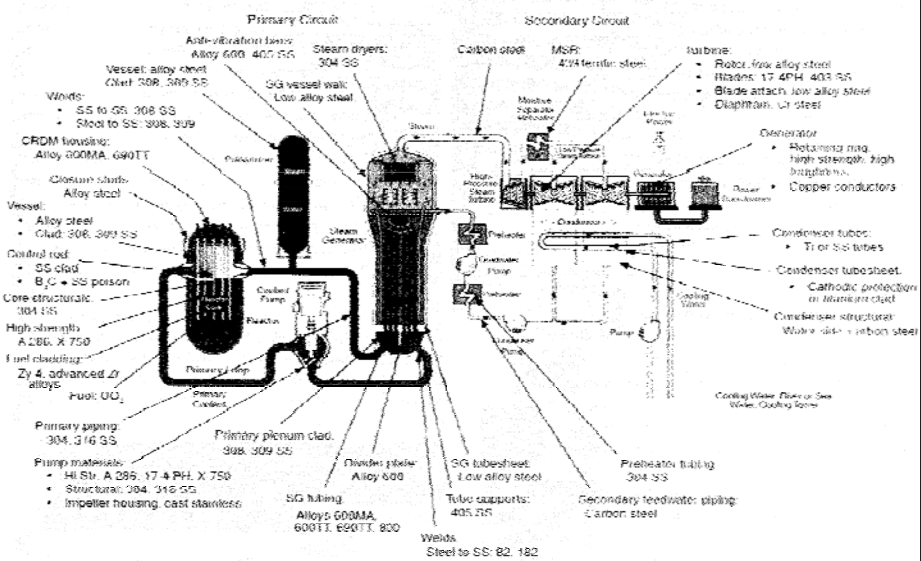


Lower concentration limit of cost-effective processing

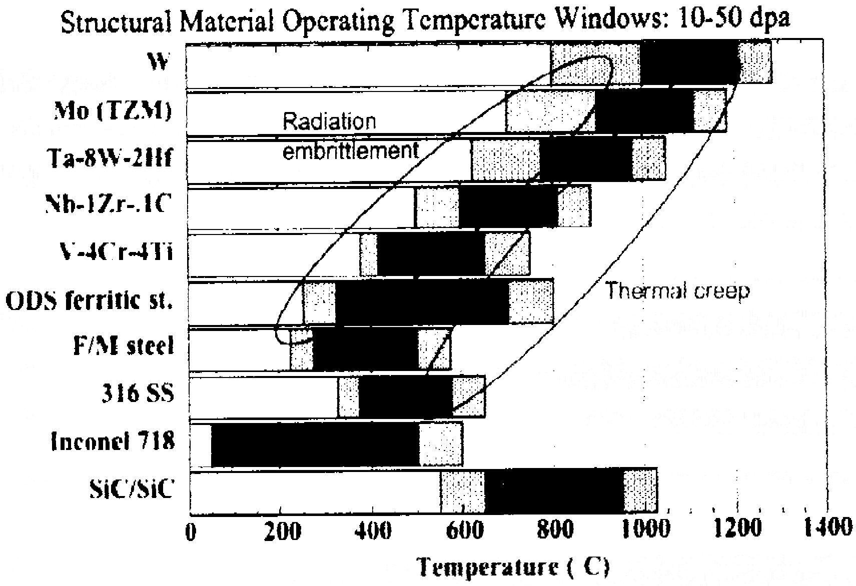
(In-Situ Leaching of Ores / N.P. Laverov *et.al.* M., 1998)

Element	Concentration limit, mg/l
Rhenium	***0,2***
Selenium	**10**
Molybdenum	**10**
Vanadium	**40-50**
Scandium	**0,3**
TR	**10**

Schematic of key components utilizing structural materials in pressurized water fission reactor



(Materialstoday. 2009, V. 12, № 11. – P.13)



(Materialstoday. 2009, V. 12, № 11. – P.17)

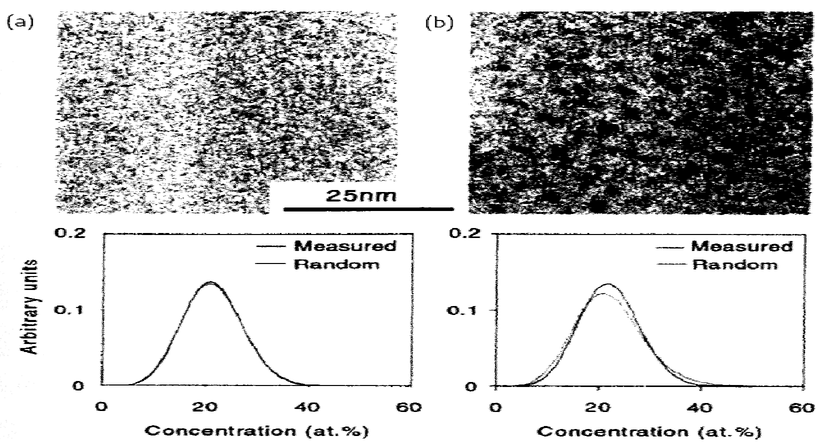


Fig. 2 5 nm thick slices through atom-probe tomography reconstructions obtained from a W-25at.%Re alloy. Only Re atoms are shown. (a) Re is in solid solution before implantation (a) and (b) clustered after implantation by 2MeV W ions at 500 °C to 2.8 dpa. (b) The concentration distributions confirm the random Re distribution before implantation and non-random one after implantation.

(Materialstoday. 2009, V. 12, № 11. – P. 32)

The use of ^{188}Re isotope in nuclear medicine

- phosphonate complexes with ^{188}Re, designed to reduce bone pain associated with metastases due to breast, lung or prostate cancer
- complexes $^{186,\ 188}$Re (V) with dimercaptosuccinic (DMSA) acid for the treatment of medullary thyroid carcinoma
- ^{188}Re-sulfur colloid-labeled albumin microspheres for tumors
- ^{188}Re-hydroxyapatite, ^{188}Re-geptasulfid
- ^{188}Re-glyukogeptonat, ^{188}Re-DTPA, intended for coronary angioplasty
- ^{188}Re-labeled lipophilic complexes diaminodithiol, Lipiodol labeled with ^{188}Re proposed for the treatment of liver metastases in prostate cancer,
- labeled somatostatin analogue Re-188-RC-160 is considered for the treatment of somatostatin receptor-positive tumors, including breast cancer cells

CONCLUSION

In the implementation of the Nuclear Fuel Cycle traditional features of associated recovery and use of rhenium are saved

- As a trace element Re is recovered from uranium multicomponent raw materials

- As a metal having high refractoriness Re is used in the heat-resistant alloys for the manufacturing of high-temperature reactors

Thank you for your attention