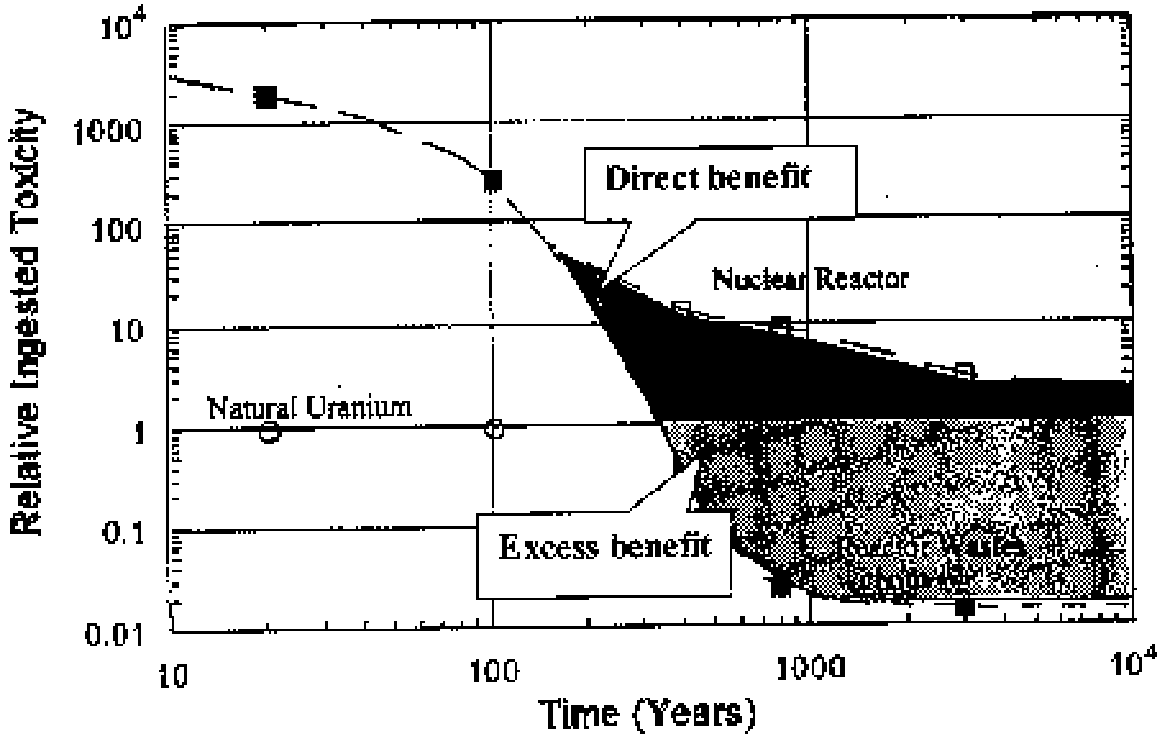
Russian Perspectives on the US ATW Program and Opportunities for Collaboration

- ☑ **ATW Philosophy and implementation**
- ☑ **ATW development issues**
- ☑ **Collaboration**

Arguments



Relative Ingested Toxicity
Time (Years)
Direct benefit
Excess benefit
Nuclear Reactor
Natural Uranium
10^4
1000
100
10
1
0.1
0.01
10
100
1000
10^4

ATW philosophy and implementation

- ☑ Impressions
- ☑ Pro et Contra
- ☑ Implementation scenario
- ☑ Funding
- ☑ Interconnection with Pu disposition program

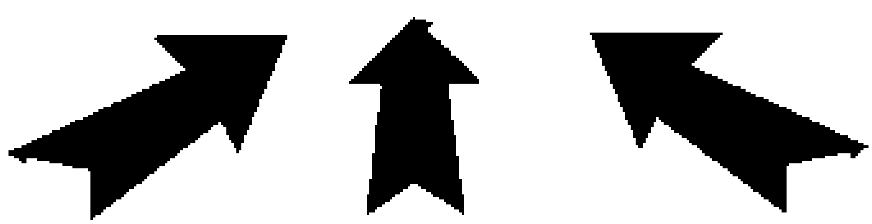
ATW Development Issues

- ☑ Key solutions are correct
- ☑ Alternative options approach is important

- ☑ Number of ATW plants should be minimized
- ☑ Danger of transfer to infinitive R&D

Key problems of target-blanket systems development.

Coolant type	Pb-Bi	
Target design	With window	Windowless (more complicate but seems more promising)
Target cooling system	Independent circuit	Joint with the one of blanket
Number of circuits	2 (economically preferable)	3
Circulation system	Forced convection	
Fuel type	TRU+Zr	
Fuel rod and assembly design	Fuel rods with ribs	Fuel rods without ribs
Invessel shielding	Intermediate heat exchangers shielding need in special care	
Equipment protection (radiation shielding) near the ion-guide	Increased activation of equipment (ion-guide, refueling machine etc.) placed at the head of facility. It promise to be the key engineering problem.	
Increased gas system radioactivity	Gaseous and evaporating spallation products release.	
Increased thermo-mechanical loading in fuel and equipment	High frequency of beam switching off and high speed of power decrease and increase.	

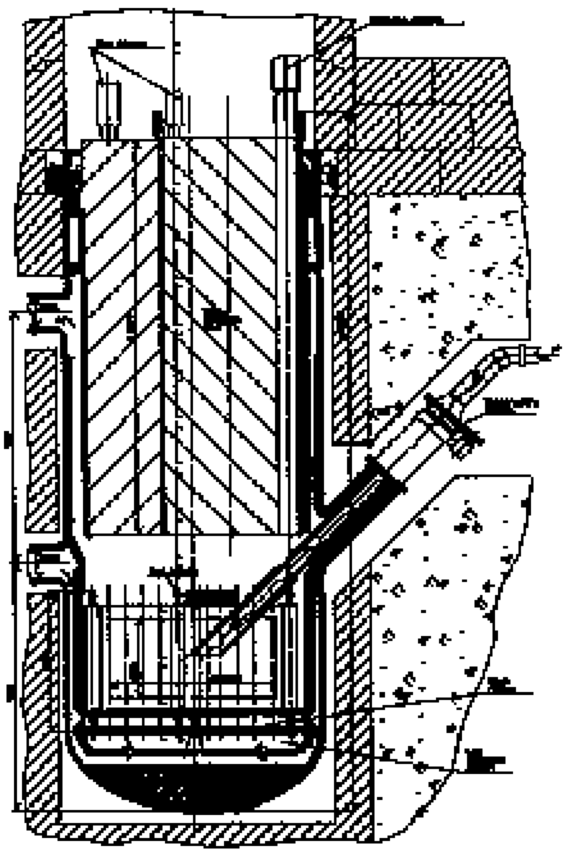


Freezing / Melting	Coolant technology	Loss of Heat Sink	Intercircuit leakage	Beam off accident

Design issues for sodium coolant

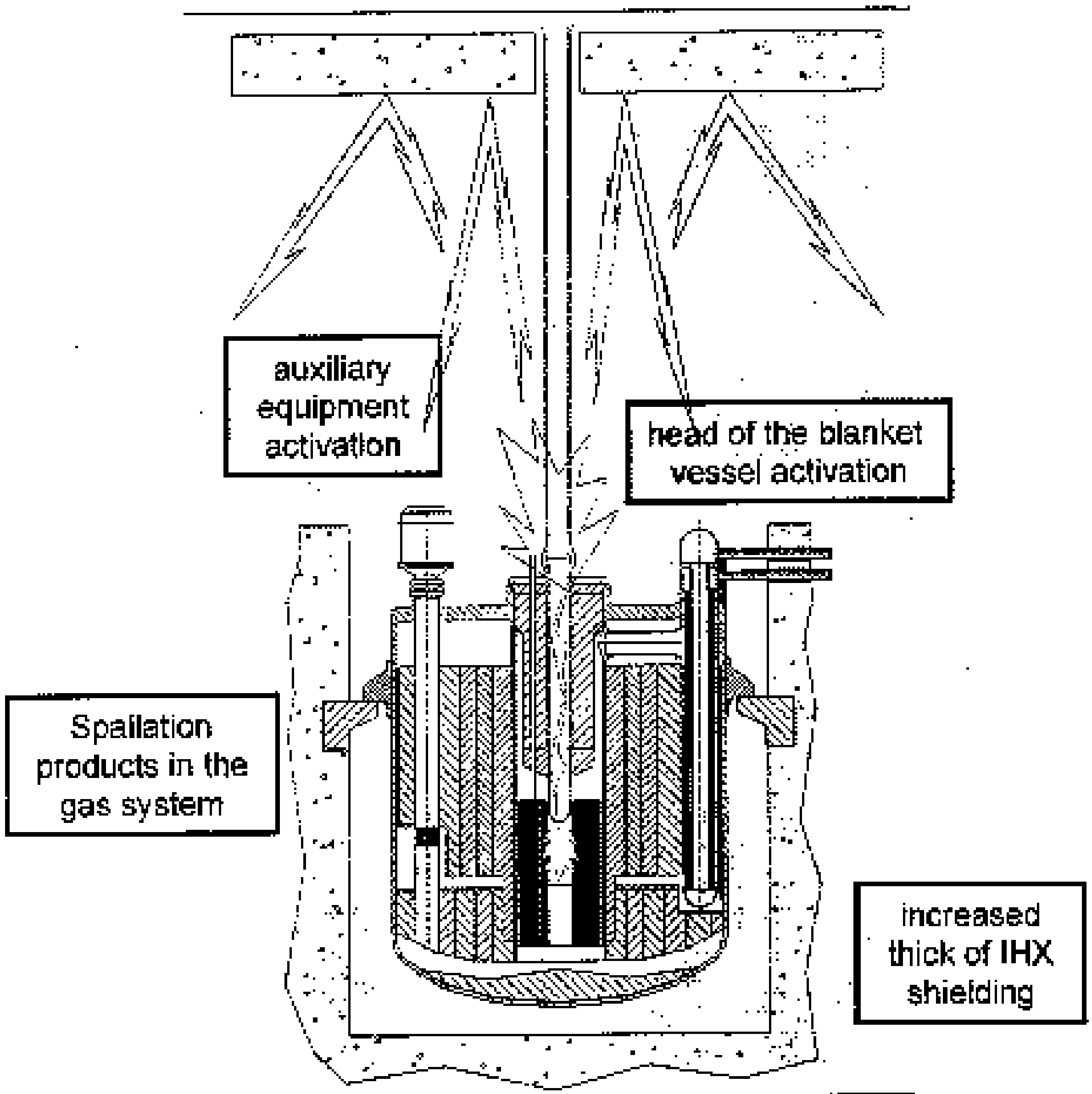
- ☑ Coolant technology & spallation products
- ☑ High coolant radiotoxicity
- ☑ Low level of natural convection
- ☑ Specific safety questions
  - chemical interactions with air and water
  - solid target overheating in LOF without beam off accident
  - secondary circuit activation
- ☑ Three-circuit design
- ☑ Big primary vessel dimensions

DEMO concept with lateral beam input



Thermal capacity, MW	500-700
Average coolant temperatures in the core inlet / outlet, ^{0}C	250 / 320
Coolant flowrate in blanket, m^3/hour	8000-10000
Coolant velocity in blanket, m/s	2
Diameter of the core, mm	2950
Effective height (on fuel), mm	1300
Generated steam parameters.	
Pressure, MPa	7
Temperature, ^{0}C	284
Steam production, t/hour	9600
Capacity of the proton beam, MW (I=14 mA, E=1 GeV)	14
Diameter of the target, mm	250
Coolant temperature in target, ^{0}C	
Inlet / outlet	250 / 320
Coolant volume in the blanket, m^3	70

ADS radiation safety and shielding issues

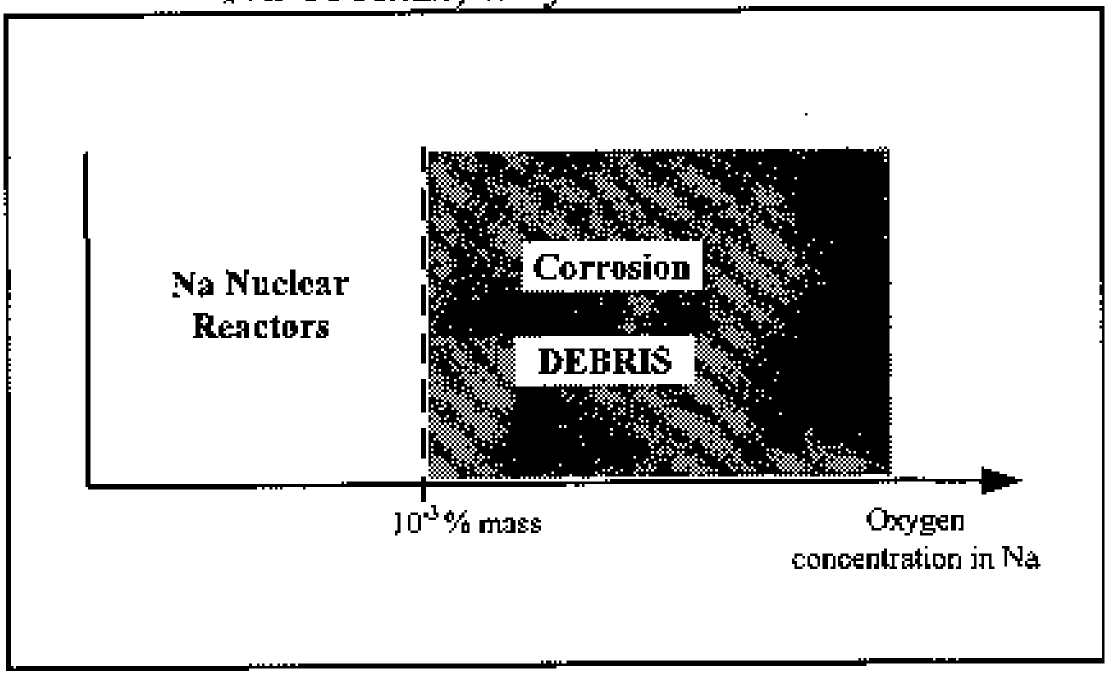


Comparison of coolant circulation types

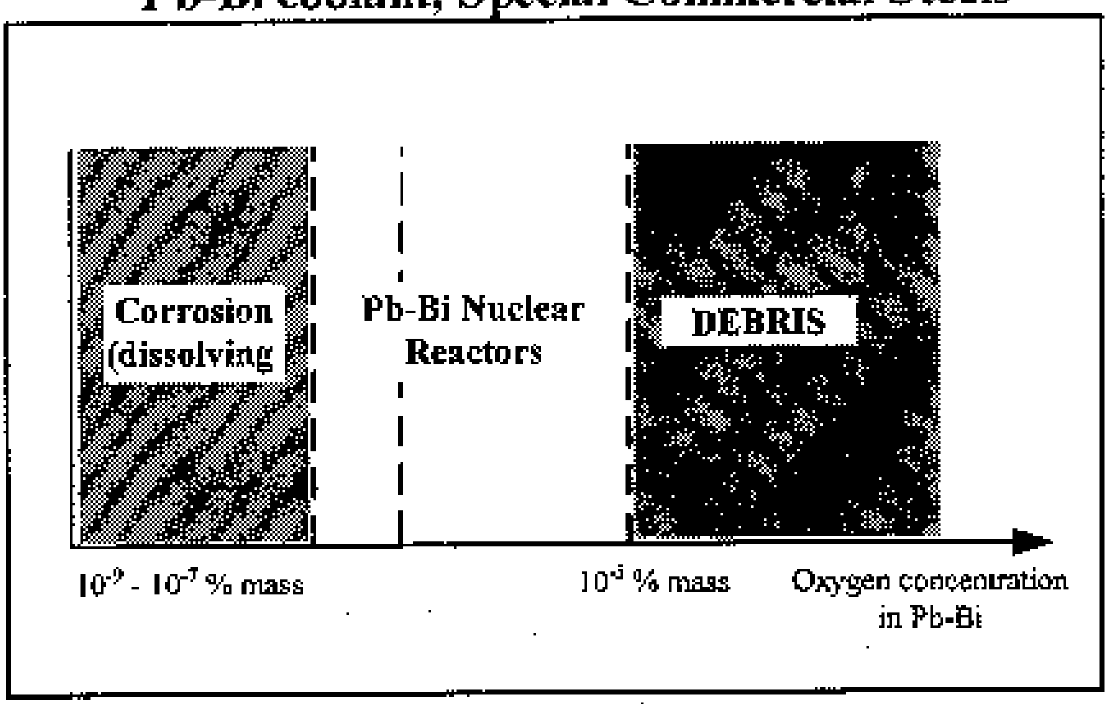
	1	2	3
Primary Pb-Bi-coolant circulation	Circulation by pumps	Natural circulation	natural convection enhanced by gas-lift, with compressor
Average power density in the core, MW/m^3	100...150	10...30	10...30
Reactor vessel dimensions (features)	Minimum	Few tens of meters in height, large in diameter	Height - larger, than for var.1, large in diameter
Coolant technology	Developed	Existing coolant technology cannot be utilized	The same, like for var. 2
Power loss for coolant circulation	Up to 2% of rated power	No	Up to 10% of rated power
Loss of nominal circulation (safety aspects)	Possible (because of pumps stop). Aftercooling (decay heat removing) - by natural convection at level ~10% of rated power. Liquid metal target removal outside the blanket is required.	Impossible	Possible (because of compressors stop). Natural convection for blanket aftercooling (decay heat removing) and liquid metal target removal outside the blanket are required.

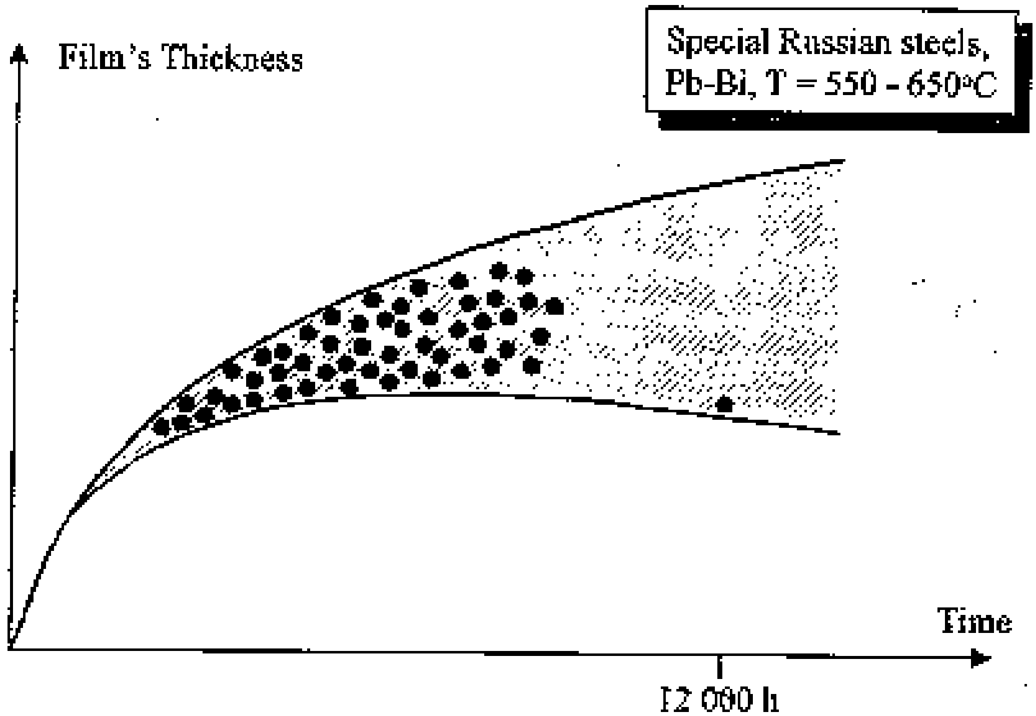
Corrosion Phenomena for HLMC

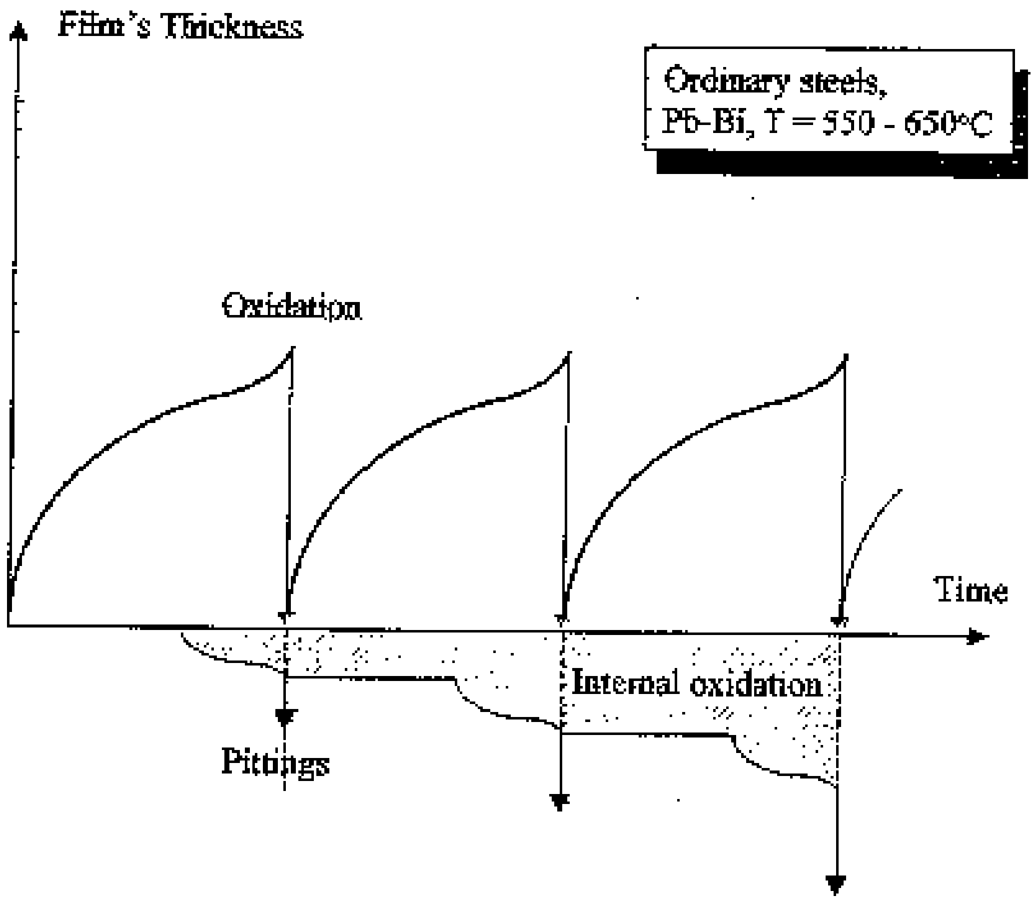
Na coolant, Any Structural Steels



Pb-Bi coolant, Special Commercial Steels




Film's Thickness
Special Russian steels,
Pb-Bi, T = 550 - 650°C
Time
12 000 h


Film's Thickness
Ordinary steels,
Pb-Bi, T = 550 - 650°C
Oxidation
Time
Internal oxidation
Pittings

STRUCTURE MATERIALS FOR ATW

Cladding (T = 550-650°C):

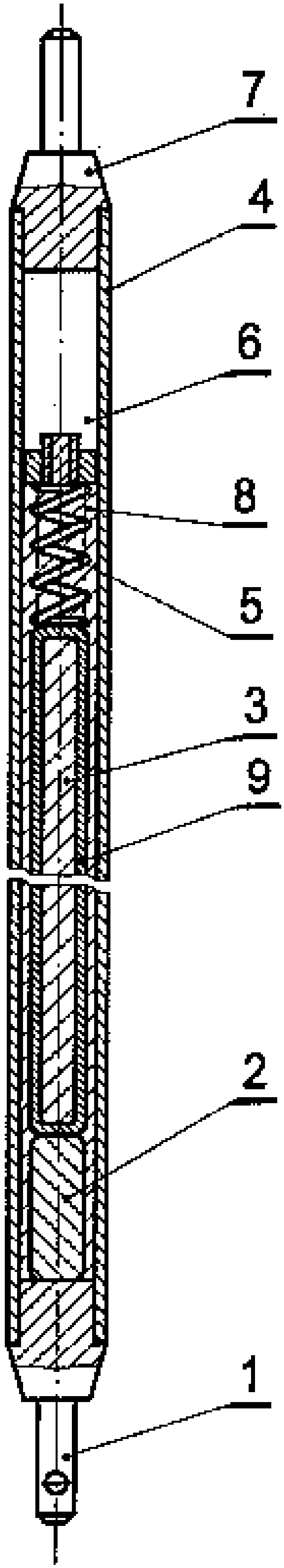
- Only Russian steels type of **EP823** steels may be used.
- More that 70000 kg of **EP823** steel have been produced on Russian metallurgical plants since beginning 70's.
- More that 25000 m of four-ribbed tubes of **EP823** steel have been produced on Russian tube's plants since middle 70's.
- **EP823 (Cr12MoNiVWNbSiBCe)** is ferritic-martencitic steel. It has excellent corrosion behavior in Pb-Bi coolant up to temperature at 650°C.
  It has good irradiation behavior after the irradiation test in BR-10, BOR-60, BN-350 and BN-600 nuclear reactors.

Internal equipment (T = 300-550°C):

- Undoubtedly, austenitic and ferritic special Russian steels may be used.
- Perhaps, some of US steels may be used instead of Russian steels.
- European (Germany, France, Italy) steels are testing now in Pb-Bi corrosion loops of IPPE.
  New corrosion loop in IPPE is ready to test US steels.

Vessel:

- Steels type of 316SS may be applied.

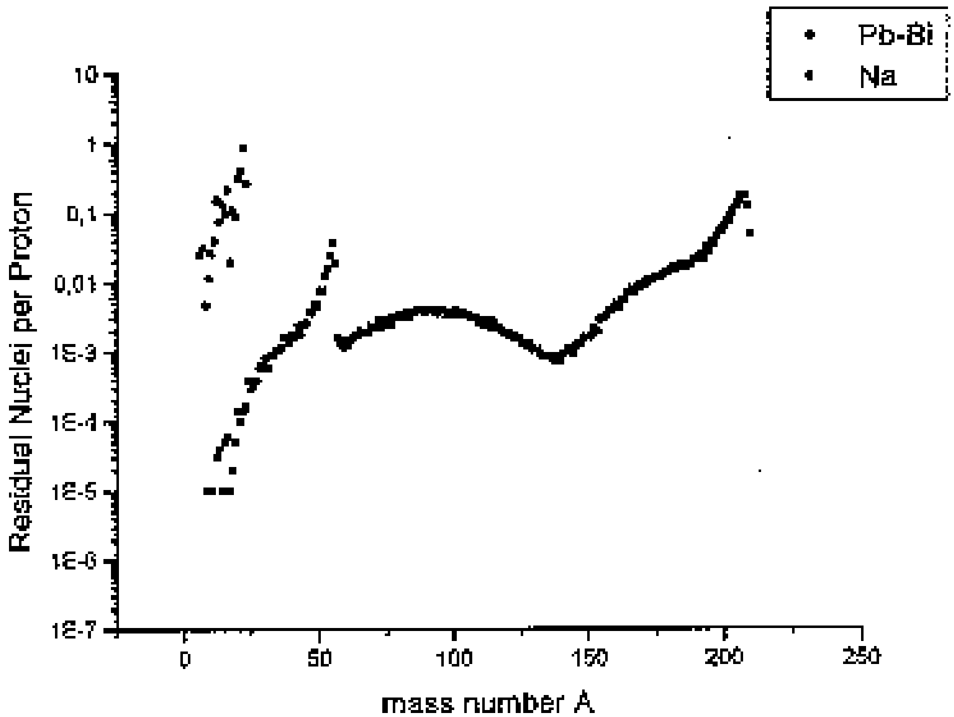


The main design characteristics of fuel

Fuel composition - Zr + Pu + MA
Heat generating rate - < 400 wt/cm
Coolant temperature - 300 / 500 °C
Maximum cladding temperature - < 600°C

1 - end plug; 2 - refractor; 3 - fuel; 4 - cladding; 5 - spring; 6 - compensator; 7 - top end plug; 8 - sodium bond; 9 - subcladding.

Long time sodium coolant activation in ADS



Radiotoxicity of target coolants, Ci (1 MW target)

Time after beam off, year	0	1	5
Na	$2.8 \cdot 10^5$	$3.87 \cdot 10^3$	$1{,}69 \cdot 10^3$
Pb-Bi	10^4	$7.5 \cdot 10^3$	$3.15 \cdot 10^3$

Polonium problem background

Generation:

$$\begin{array}{ccccc} Bi^{209} + n \rightarrow Bi^{210} & \xrightarrow{\beta^-} & Po^{210} & \xrightarrow{\alpha} & Pb^{206} \\ & T_{1/2} = 5\,days & & T_{1/2} = 138\,days & \end{array}$$

Activity: $A_{210}^{coolant} \approx (1.0 \div 1.5)\, Ci/kg$

Possible consequences of coolant leak:

- **α-radioactive aerosols in the air ;**
- **α-contamination of surfaces due to aerosols sedimentation and contact transfer.**

Rules:

Maximum Po^{210} -concentration in servicing compartments air should not exceed 2.7 Bq/m^3 (7.3*10^{-14} Ci / liter).

Experience:

- **Several leakages in amount up to 2,000 kg with α-radioactivity in compartment air about 10^{-12} Ci / liter.**
- **No any case of personnel overirradiation caused by Po.**
- **Methods and means developed to provide safety and to localize radioactive contamination.**

Polonium in ADS.

One year of operation. 1 MW target.		
Important isotopes & its origin	**Activity in the coolant, Ci / kg**	**Activity in ~0.1m^3 target gas system, Ci / liter**
Po^{210} (capture)	**0.52**	**4.0*10^{-12}**
Po^{209} (spallation)	**4.2*10^{-3}**	**4.1*10^{-12}**
Po^{208} (spallation)	**0.41**	**4.3*10^{-10}**

Radioactive air contamination under loss of tightness conditions in the target gas system will be determined *not by polonium isotopes*, but by Xe^{127} and Xe^{125} - products of coolant nuclei fission by high-energy protons.

Pb-Bi technology

- Systems & devices
  - Oxygen measurement
  - Oxygen control
- Materials
  - Special steels
  - Preparation for use
- Regulations
  - Depends on design features
  - Design limits

Opportunities for Collaboration

Conditions

- Mandatory condition - warranty of unmilitary use
- Additional - maintenance of profit for Russia

Areas of cooperation

- Development of the conceptual design projects.
- Development, manufacturing and delivery of separate elements of the equipment
- Realization of part of experimental & technological works in Russia