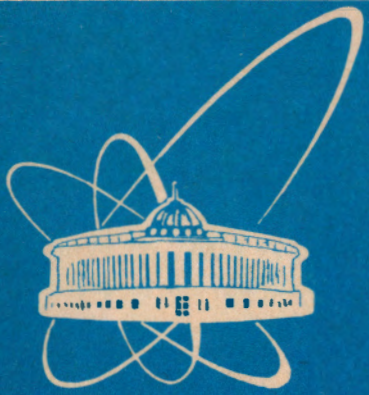

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RECENT DEVELOPMENT OF RADIOANALYTICAL METHODS AT THE IBR-2 PULSED FAST REACTOR

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Применение радиоаналитических методов
на импульсном реакторе ИБР-2

Обсуждается опыт использования радиоаналитических методов, включая нейтронный активационный анализ (НАА), на импульсном реакторе ИБР-2. Подробно рассматриваются установки для работ с применением НАА и радиографии. Приводятся примеры использования резонансных нейтронов для мониторинга состояния окружающей среды и изучения сверхчистых материалов.

Работа выполнена в Лаборатории нейтронной физики им. И.М.Франка ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 1994

Nazarov V.M., Peresedov V.F.
E3-94-437

Recent Development of Radioanalytical Methods
at the IBR-2 Pulsed Fast Reactor

Experience in the application of radioanalytical methods, including NAA, at the IBR-2 pulsed fast reactor is reviewed. Details of the instruments dedicated to neutron activation analysis and radiography studies are reported. Applications of resonance neutrons to environmental monitoring and to the investigation of high-purity materials, are examplified.

The investigation has been performed at the Frank Laboratory of Neutron Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna, 1994

Introduction

All investigations in FLNP are mainly performed at two sources of neutrons. One of them is the pulsed reactor IBR-2, the second - the multiplier (booster) with a linear electron accelerator.

Here we shall speak about the investigations at IBR-2 /1/. The IBR-2 is a high flux pulsed reactor of periodic operation. The principle of its operation is schematically illustrated in fig.1. Two steel moveable reflectors are rotated near the PuO_2 active core. The main moveable reflector (MMR) rotates with the frequency of 25 Hz; and the auxilary moveable reflector (AMR), with the frequency of 5 Hz. The reactor becomes subcritical when both reflectors pass simultaneously by the active core. Thus periodical pulses of power develop. The duration of the fast neutron pulse at half-width is equal to 215 μs. The peak power in pulse is 1500 MW at average thermal power of the reactor of 2.0 MW.

One can see from the time dependence of reactor power presented in fig.2 that it has a rather complicated character. It has a permanent background and small satellite pulses appearing with the frequency of 25 Hz in between the power pulses of frequency 5 Hz. However the total power between main pulses is not high and equals 0.1 MW.

The IBR-2 has four light water moderators, three of which are positioned behind stationary tungsten reflectors, and the fourth behind the moveable reflectors. Two moderators are made in the form of a comb (grooved type, Nazarov's type moderator (NTM)). It provides an increase of the density of the thermal neutron flux by a factor of two in comparison with the optimal plane moderator 5 cm thickness. At the same time the yield of cold neutrons with the wavelength of more than 4 Å increases by 5 times without any additional cooling/2/.

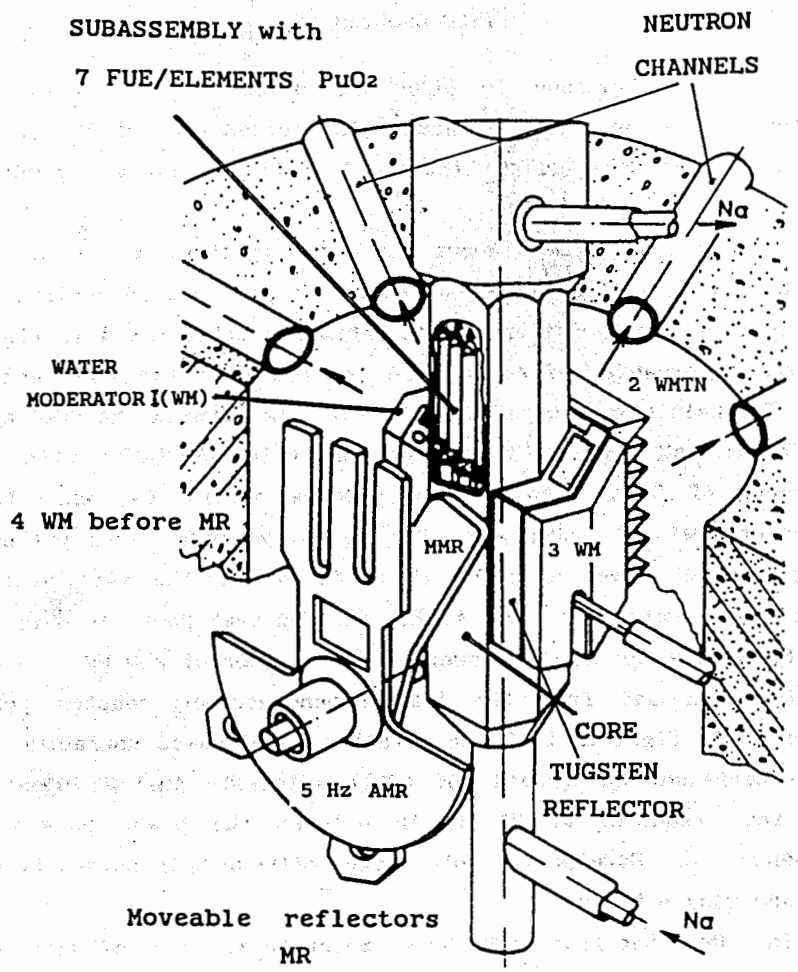

Fig. 1. Schematical view of the IBR-2 reactor. MMR - main moveable reflector (25 Hz). AMR - auxilary moveable reflector (5 Hz). WH - water moderators, WMTH - Nazarov's type moderator.

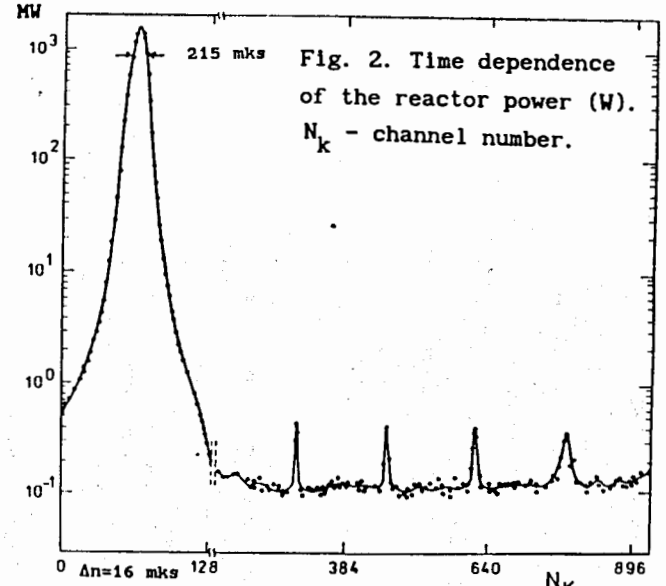

Fig. 2. Time dependence of the reactor power (W). N_k - channel number.

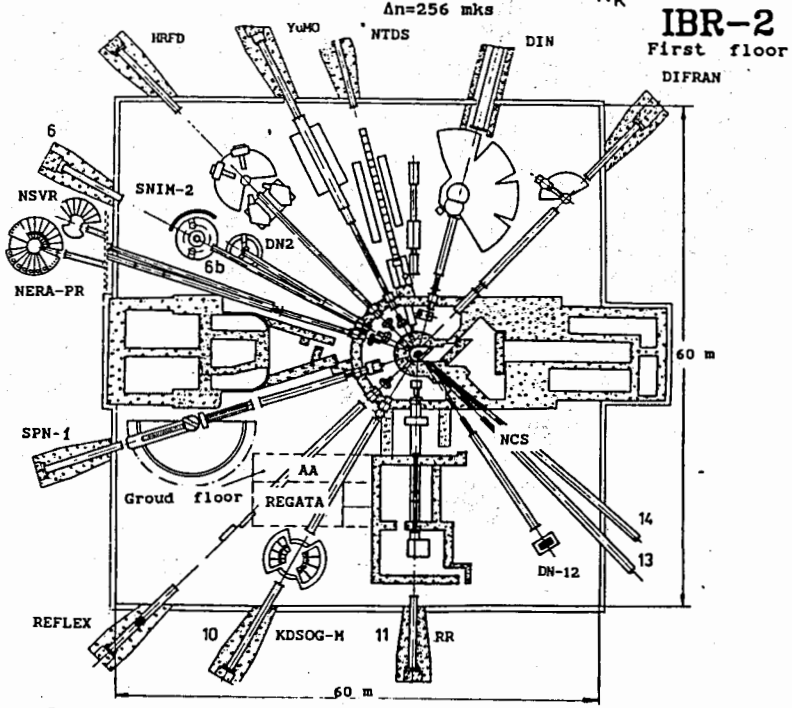

Fig. 3. Schematic layout of the IBR-2 experimental channels. AA - rooms for the neutron activation analysis. "Regata"- pneumatic system.

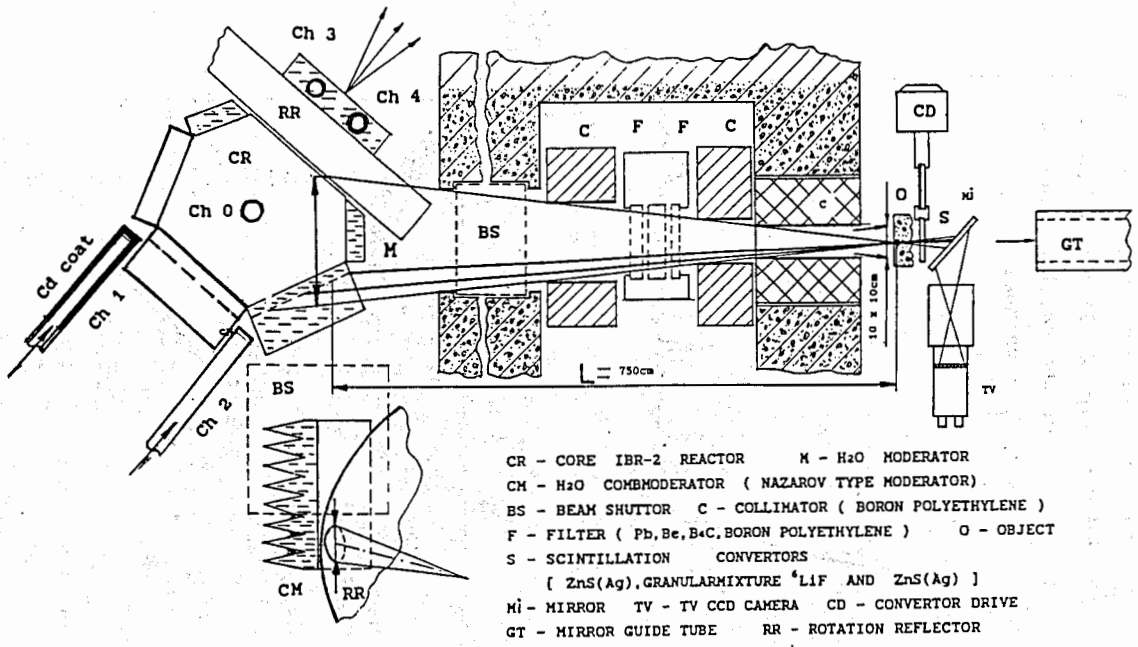

Fig. 4. The neutron channel for Radiation Research (first part) with Ch1, Ch2, Ch3, Ch4, Ch0 - irradiation channels.

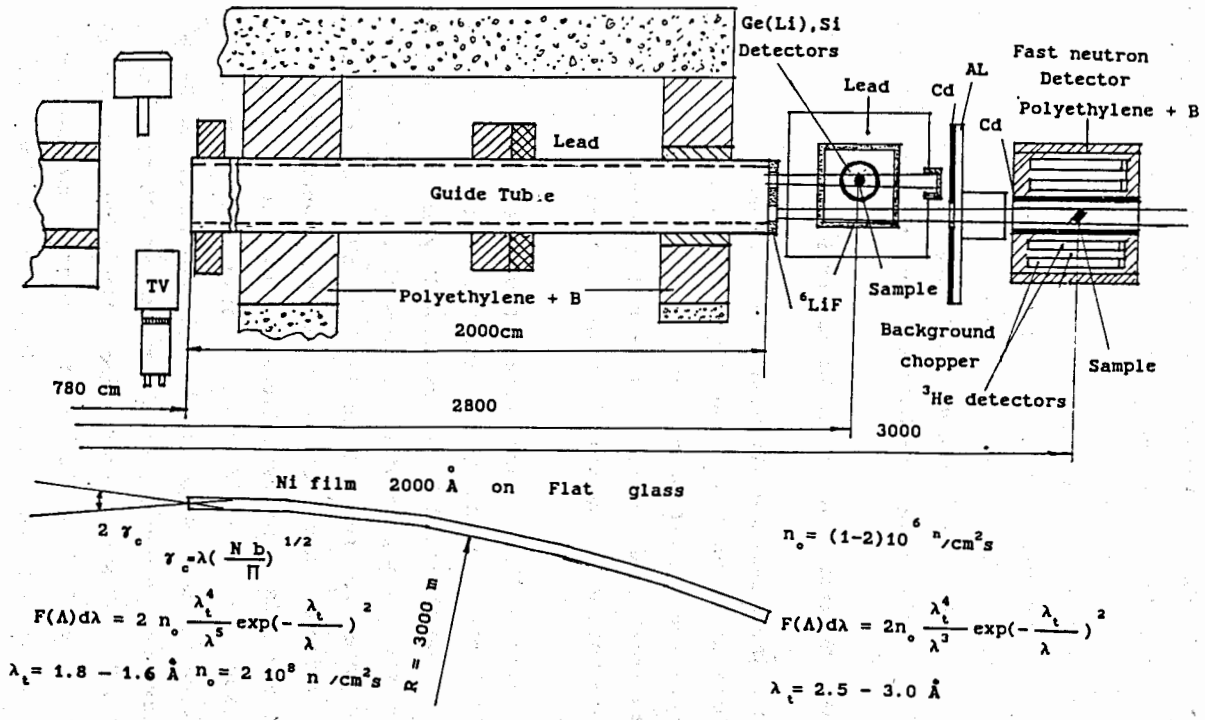

Fig.5. Continuation of the neutron channel for Radiation Research. $F(\lambda)d\lambda$ - the netron flux per unit of λ, where λ is an interval of the wavelengthes (λ). n_o - flux of the thermal neutrons at the sample position.

From the moderators through the double-wall biological shielding 14 horisontal channels go (fig.3) at which 15 experimental setups are arranged.

At these channels, excluding channels 3 and 11, investigations in condensed matter physics and subatomic physics are being performed. The experiments are carried out using elastic, inelastic and small angle scattering of neutrons, in combination with time of flight technique, diffraction and interferometry of neutrons.

The RR - Neutron Channel for Radiation Research

There are 3 instruments positioned at 7.5, 28 and 30 m from the reactor core at channel 11 (see fig.4 and 5) and equipped with devices to shape neutron beams for:

- conventional static and dynamic neutron radiography;
- elemental analysis with the aid of prompt neutron capture
- reactions;
- radiation studies with fast and thermal neutrons.

Conventional static neutron radiography studies are carried out on all of the above sited flight paths and dynamic radiography studies just on the 7.5 m path with the possibility of varying the neutron energy interval from 1.0 up to 10^{-3} eV, and using high sensitive TV-vidicons and related video-equipment. With the $^{6}Li+ZnS$ converters this equipment allows one to have the image in one reactor flash. The sizes of scanning beams can be varied by remote controlled (20 s) change of the collimators of 20×20 cm^2, 10×10 cm^2 and 5×5 cm^2. A device for the automated (15 s) change of filters: Pb, B_4C, Be and polyethylene with boron, views the collimator. In tables 1, 2 the list of the average characteristics of the RR-neutron channel for radiography and radiation research are given.

The pulsed characteristics are seen from presented in fig. 6

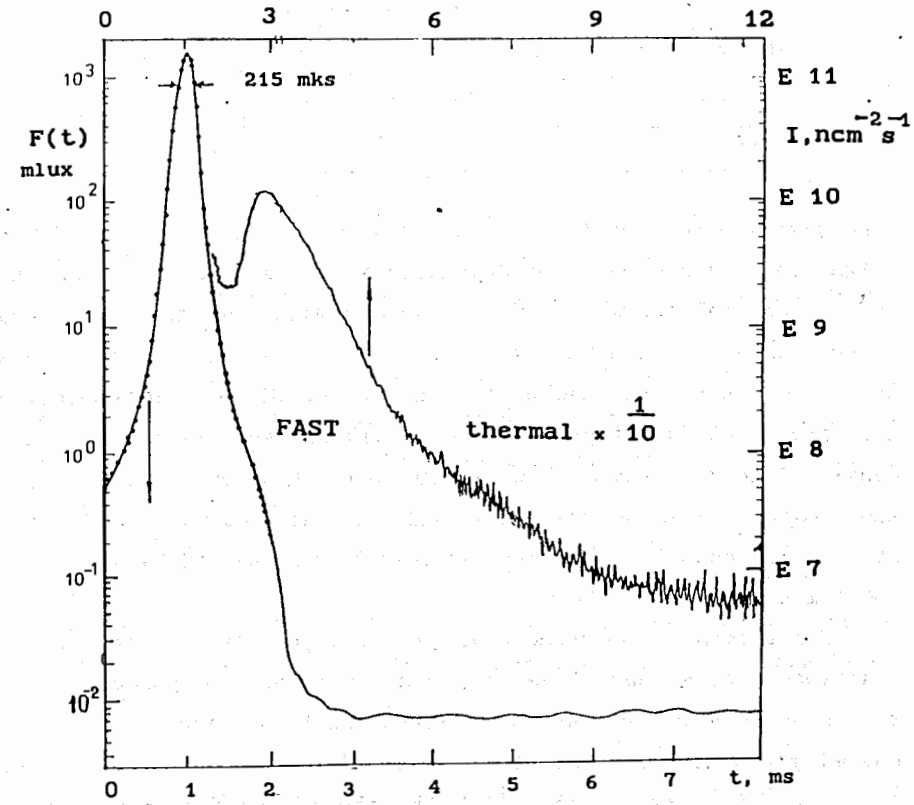

Fig. 6. Time distributions: for the flux densities of the fast and thermal neutrons (I) and for the luminifer brightness F(t).

Table 1. The List of the Characteristics of the RR-Neutron Channel for Neutron Radiography

Visible moderator	Average Neutron flux density(n/cm^{2}s)			L/D ratio	Imaging Technique		Neutron exposure time(s)
	Thermal	Reson.	Fast		Screen	Instrument	
Radial	2×10^8	1.3×10^7	8.4×10^8	36	Gd	Film	20
					$ZnS+^6LiF$	CCD TV camera	20×10^{-3}
Tangential	0.7×10^8	0.3×10^7	3×10^8	240	Gd	Film	60
					$ZnS+^6LiF$	CCD TV camera	20×10^{-3}

Here D - the effective radiating surface of the moderator,
L - the site at the distance of 7.5 m.

Table 2. Some Additional Characteristics of the RR-Neutron Channel for Radiation Research

Filter type	Dose rate of fast neutrons (GY/min)	Dose rate of γ-rays (GY/min)
no	1.0	0.26
lead 4 cm	0.4	0.008

time distributions of the fast and thermal neutrons on the 7.5 m flight path. Here the time dependences of the brightness of the ZnS(Ag) and ZnS(Ag) with ^{6}LiF monitors created by the fast and thermal neutrons, respectively, at the L/D=240 are shown. These dependences were obtained by the use of the Ultra-high-resolution Monochrome CCD 8410 type camera of 0.013 lux sensitivity with the dynamic interval from 10^{-2} up to 10^{3} lux. It allows to radioscope the samples both by the fast and thermal neutrons with beam attenuation down to 10^{5} times. At present we use the TV camera of 100 times worse sensitivity.

For elemental analysis using (n,γ), (n,α), (n,p) and (n,f) reactions a pure thermal neutron beam is shaped and guided to the 27 m site by means of the curved mirror neutron guide, made of Ni-coated glass in the form of a rectangular tube 20 m long and 15×150 mm^2 in cross-section with the thermal neutron flux outlet density of 2×10^{6} n/(cm^{2}s)/3/. The Ge(Li) and Si-detectors are used as analysers. The content determination of samples of fissionable isotopes (^{235}U, ^{239}Pu) by using prompt and delayed neutrons will be carried out at the 30 m site equipped with the Cd mechanical chopper (fig.5), which, together with the curved neutron guide of 3000 m radius, practically completely cuts the background of fast and thermal neutrons in between the reactor pulses. In the detector of fission neutrons the He-counters enveloped in the polyethylene moderator are used. The expected absolute detection efficiency of this detector for fission neutrons is nearly 20 % /4/. The thermal neutron flux density on the sample with the chopper in the beam is 10^{6} n/(cm^{2}s).

For conducting the activation analysis and radiation studies and to produce radioactive isotopes the IBR-2 reactor has five channels, Ch0-Ch4, equipped for sample irradiation (see fig. 4) Two channels, Ch1 (with a Cd-coated screen) and Ch2, are connected to the pneumatic system "Regata". Samples are transported to experimental sites with the aid of compressed air.

All channels are dry in their inside with Ch1 and Ch2 being air-cooled, Ch3 and Ch4 water-cooled and Ch0 liquid sodium cooled.

The time of sample irradiation in channels Ch3 and Ch4 depends on the operation cycle duration of the reactor and is equal to 10-12 days. The main parameters of irradiation channels are given in table 3.

All the parts of "Regata" system are situated far from the reactor core (30-40 m) and occupy three special rooms (see fig.3).

The transportation time to and back from irradiation sites is 10-15 seconds. Up to 7 containers can be simultaneously irradiated in each channel.

"Regata" is equipped with a device for the fast (3 s) extraction of capsules with irradiated samples from the polyethylene

Table 3. Summary of the Characteristics of the Irradiation Channels at the IBR-2 Reactor.

Irradiation site	Neutron flux density (n/cm^{2}s)×10^{12}			T°, C	Chan. diam., mm	Chan. length, mm
	Thermal	Resonance	Fast			
Ch1	Cd coat	0.23±0.03	1.4±0.16	70	28	260
Ch2	0.54±0.06	0.12±0.014	0.64±0.04	60	28	260
Ch3	Gd coad	0.9±0.10	7.0±0.5	20-30	35	400
Ch4	13.0±0.5	1.25±0.1	7.0±0.5	20-30	35	400
Ch0	no	< 0.1	150	400	16	180

transport container, which is important when a short-lived (within one second range) isotope is studied. The transport container is often used as a capsule. Its internal volume is 5 cm^3, the outer diameter is 26 mm. The volume of the aluminium container is 1.8 times larger than that of the polyethylene one but it has the same external parameters.

In polyethylene containers samples can be irradiated for up to 10-20 minutes and in aluminium - for the longer periods of irradiations of 10 days and more.

To serve the aims of activation analysis the system "Regata" is equipped with measuring modules operating on the basis of an IBM PC(AT) set of programs for neutron activation analysis as described in /6/. That consists of the programs for γ-spectra processing with automatic peak search, and for the identification of elements and determination of their concentrations by the following procedures: using a neutron flux, one or two isotope comparator, and using standards. This set of programs also includes the data base for the isotopes formed in interactions of neutrons with nuclei.

Use of Irradiation Channels

The irradiation channels at IBR-2 serve the following investigations:

- Use of moss, lichens and pine needles as biomonitors of atmospheric depositions of heavy metals and REE measured mainly by means of the INAA in resonance neutron beams/7,8,9,10/.
- Use of resonance and thermal neutrons for tracing the transport of heavy metals and RE elements by aquatic ecosystems for the purposes of biomonitoring/11/.
- INAA of geological samples aimed at the determination of RE elements along with other trace elements/12,13/.

- Use of INAA for identifying trace or impurity elements in high-purity materials such as Si, Al, Be, polymers and organic solvents/14,15 /.
- Concentration analysis of impurity or trace elements in synthetic and natural crystals (preclous stone) like topaz, corund and beryl, aimed at the study of the impurity atoms influence on the formation of radiation (neutron) dye centres.
- There is a possibility for radioisotope production in Ch0 with (n,p), (n,α)-reactions and in Ch4 with (n,γ)-reactions. Capabilities for the production of some isotopes are illustrated in table 4.

In 1993 work on INAA application for investigations of moss and pine needles as biomonitors in the Tver District, near Dubna, in Kola Peninsula (in the regions close to nickel melting plants)

Table 4. Data for Some Isotopes the Radiochemical Separation of Which is Developed in the JINR

No	Target	Reaction	Isotope	$T_{1/2}$, days	Production mC/10 days** irradiat.	Approximate price, $/mC
1.	^{33}S	(n,p)	^{33}P	25.2	10000	-
2.	^{54}Fe	(n,α)	^{51}Cr	27.7	200	20
3.	^{58}Ni	(n,p)	^{58}Co	70.8	7000	50
4.	^{67}Zn	(n,p)	^{67}Cu	2.44	500	100
5.	^{74}Se	(n,p)	^{74}As	17.7	2000	-
6.	^{59}Co	(n,p)	^{59}Fe	45.1	200	50
7.	^{124}Xe	(n,γ)	^{125}I *	60.14	10000	2.0

* The isotope of super purity with the impurity of ^{126}I at the level of 10^{-4} Bq/Bq only, is produced in the channel Ch4.

** Production is given for targets 1-6 of 10 g weight, and for the ^{125}I gaseous target of 10 cm^3 volume at the pressure of 5 atm.

and in some regions of Norway began. Lichens were from the Franz Josef Land/10/.

The INAA procedure using the Ch1-Ch4 irradiation channels was developed for this purpose. It has been shown that the best results with respect to long lived isotopes for above natural monitors were obtained in channels Ch1 (Cd coat) and Ch3 (Gd coat). An intercomparison of moss reference materials DK-1 /9/ was also performed.

Some Examples of INAA at the IBR-2

In Ch1 and Ch3 we can reliably determine, for example in DK-1, 45 elements including 10 REE's, namely: Na, Mg, Al, Cl, K, Ca, Sc, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Br, Rb, Sr, Zr, Mo, Ru, Ag, Sn, Sb, I, Cs, Ba, Ta, W, Au, Hg, Th, U, and REE (La, Ce, Nd, Sm, Eu, Gd, Tb, Tm, Yb, Lu). In pine needles 39 elements have been determined reliably. Zr, Ru, I, Hf, Hg and U were not identified, but Cd was determined in addition.

In lichens, if compared with a set of element characteristics for mosses, such elements as Al, Ru, W, Hg, Th and U disappear if only the Ch1 channel is used. The results of such investigation for DK-1, the Usnea SP lichen and pine needles are summarized in tables 5 and 6, where the detection limits are shown for pine needles from the Kola Peninsula. The presented values of detection limits are close for mosses and lichens. The Ch4 channel with thermal neutrons is extremely seldom used by us for the determination of elements which cannot be determined in other channels.

Detection limit differences, when the Ch1 or Ch3 channels are used, are illustrated in the form of hystograms in fig.7. One can see that the use of the Ch3 channel allows more reliable determination of the content of many elements in pine needles.

Visible decrease of the detection limits for many elements in

Table 5. The Element Concentration in Moss Samples *Hilocomium Splendens*, Lichen Ones *Usnea* sp, Pine Needles *Pinus Sylvestris L*, and the Detection Limits for Pine Needles as Measured in Irradiation Channels 1 and 3

Element	Element concentrations, ppm				$\frac{I_o}{\sigma_o}$
	Moss DK-1	Lichen Usnea SP	Pine needles	Concentr. limit	
Na	530(8)	900(5)	121(5)	5.0 [1]	0.59
Mg	< 800	8200(10)	2500(15)	600 [1]	0.68
Al	480(5)	< 50	750(5)	20 [1]	0.74
Cl	328(11)	57(20)	810(20)	100 [1]	0.69
K	3300	1800(40)	5000(8)	190	0.97
Ca	1630(3)	5100(46)	2500(35)	340	1.31
Sc	0.16(13)	2.0(8)	0.043(15)	1.0E-3	0.44
V	6.0(10)	17.0(6)	2.2(17)	0.6 [1]	0.55
Cr	1.9(8)	3.2(8)	1.9(15)	0.1	0.53
Mn	143(7)	53.0(4)	198(5)	3.5 [1]	1.07
Fe	575(9)	2200(8)	194(17)	2.0	1.30
Co	0.26(5)	2.23(7)	6.8(7)	5.0E-3	2.02
Ni	1.58(21)	2.70(15)	190(5)	0.3	(n,p)
Cu	240(25)	< 20	280(8)	25 [1]	1.06
Zn	30.8(13)	21.4(5)	21.0(6)	0.3	1.96
As	0.64(3)	0.12(8)	2.0(8)	4E-2	14.0
Se	0.43(9)	0.22(13)	1.1(13)	6E-3	10.9
Br	13.5(7)	5.8(6)	2.46(6)	3E-2	19.3
Rb	12.9(7)	1.8(9)	24.8(8)	0.5	14.8
Sr	33.0(4)	23.8(17)	3.9(22)	0.8	4.1
Zr	11.0(11)	13.0(15)	< 0.7	0.7	282
Mo	< 1.4	< 0.3	7.3(27)	1.4 [1]	53.1
Ru	0.16(25)	< 0.1	< 0.01	0.01	3.63
Ag	0.05(8)	0.02(7)	0.27(12)	3E-3	17.7
Cd	< 0.1	< 0.1	0.15(27)	2E-3	48.0
Sn	2.4(15)	1.7(10)	5.7(18)	2E-3	49.1
Sb	0.37(6)	0.02(7)	0.36(9)	6E-4	28.8
Te	< 0.1	< 0.1	0.11(37)	0.1	1.7
I	3.8(8)	3.0(4)	< 1.0	0.1 [1]	24.8
Cs	0.29(7)	0.016(9)	0.046(8)	3E-3	18.5
Ba	18.5(8)	2.5(12)	2.0(46)	0.3	23.5
Hf	0.21(14)	0.12	< 0.002	2E-3	2.52
Ta	0.026(14)	0.016(13)	0.00057(20	2E-4	33.3
W	0.73(27)	< 0.2	0.34(12)	6E-2 [1]	13.7
Re	< 0.001	< 0.001	0.0022(23	1.0E-3	15.3
Ir	< 0.0003	< 0.0002	0.0007(20	5E-4	5.8
Au	0.00074(20	0.0008(8)	0.0073(7)	5E-5	15.7
Hg	0.67(10)	< 0.05	< 0.02	2E-2	0.88
Th	0.2(5)	< 0.02	0.0021(9)	1.0E-3	12.0
U	0.19(5)	< 0.02	< 0.015	2.0E-2	102.3

1 - detection limit for Ch1 channel.

Table 6. The Concentration of REE in Moss Samples *Hilocomium Splendens*, the Lichen Ones *Usnea* sp, Pine Needles *Pinus Sylvestris L*, and the Detection Limits for Pine Needles in Channel 3

Element	Element concentrations, ppm				$\frac{I_o}{\sigma_o}$
	Moss DK-1	Lichen	Pine needles	Detect. limit	
La	1.22(7)	1.07(9)	0.13(13)	3.0E-3	1.24
Ce	2.92(8)	2.38(10)	0.16(19)	5.0E-2	0.82
Nd	0.92(26)	2.55(16)	0.56(15)	2.0E-2*	2.35
Sm	0.23(8)	0.46(6)	0.013(8)	1.4E-4[1]	14.4
Eu	0.042(24)	0.060(11)	0.001(29)	5.0E-4[1]	0.67/5.67**
Gd	0.21(14)	< 0.1	0.026(16)	1.0E-2	2.75
Tb	0.022(9)	0.089(8)	0.002(20)	5.0E-4	17.2
Tm	0.015(13)	0.14(6)	0.0019(30)	1.4E-3*	17.9
Yb	0.054(40)	0.012(10)	0.0065(28)	4.0E-3	0.44
Lu	0.028(29)	0.096(8)	< 0.002	2.0E-3	2.26

* without Gd coat, ** for ^{152}Eu

1 - detection limit for Ch1 channel.

Table 7. Distribution of Some Elements Concentrations with the Confidence Intervals (μ) in Pine Needles vs the Distance (L) from the Nickel Melting Plant of Monchegorsk (Kola Peninsula) and in the Tver Region

L,	CONCENTRATION						
km	Ni	Co	Ag	Sb	Ir	Zn	Cs
12	248±92	12.5±7.5	0.34±0.11	0.28±0.1	0.73	35±16	0.02±0.01
20	131±34	9.8±5.6	0.15±0.045	0.13±0.05	0.4	62±44	0.035±0.01
50							
55	26±1.4	1.2±0.55	0.063±0.026	0.058±0.03	0.11	19±5	0.061±0.02
65	13±4.3	0.52±0.15	0.024±0.01	0.024±0.01		45	0.64±0.33
85	9.5±0.7	0.25±0.11	0.04	0.05±0.02		40±20	0.63±0.1
120	10.6±3.1	0.31±0.1	0.04±0.015	0.041±0.03		34±11	0.84±0.15
T.R	2.0±1.2	0.17±0.08	0.019±0.006	0.04±0.024		36±12	0.044±0.02

Here $\mu = SD \times t/\sqrt{n}$, t - student's factor for significance level of 0.05, SD - Standard Deviation, n - number of measured samples. Distributions for Se are analogous to distributions of first four elements and for Sr and Ba are analogous to Zn. Each averaged sample was selected from 5 trees of 100 m^2 area.

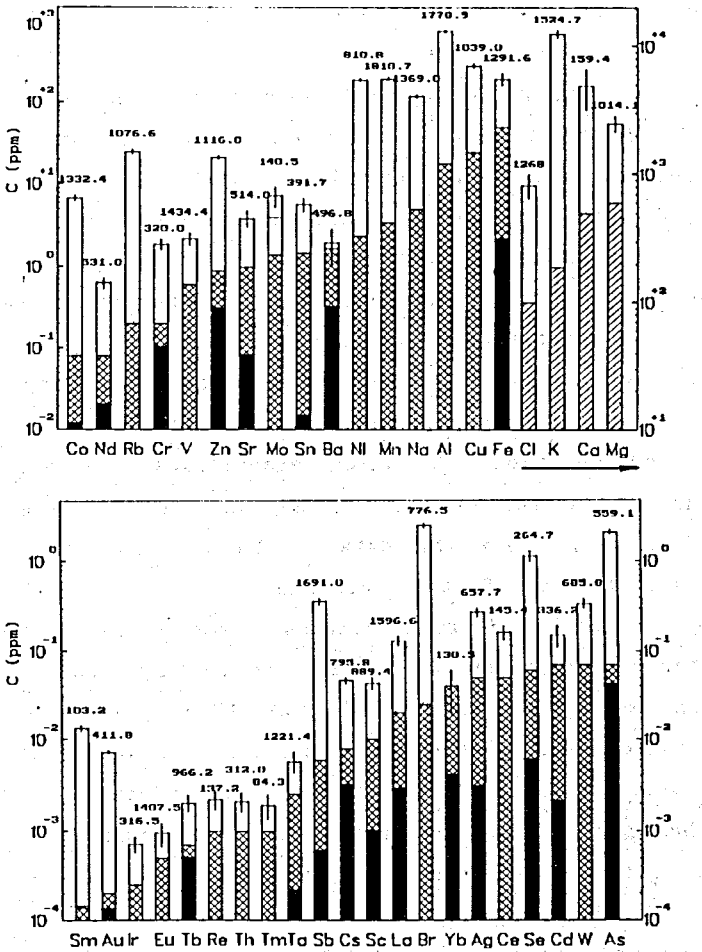

Fig. 7. Histograms of the detection limits for pine needles in Ch1 and Ch2 irradiation channels. Dashed columns are the detection limits for Ch1 channel, blacken columns for Ch3 channel, white columns are the element concentrations in pine needles.

Ch3 (Cd coat) channel is caused by that Gd in comparison with Cd absorbs effectively the neutrons with higher than 0.55 eV energy. When Gd of 100 μm thickness is used in Ch1 channel, the resonance neutron spectrum at E>0.55 eV is proportional not to $1/E^{1+\alpha}$, but to $(1/E^{1+\alpha})\times\exp(-2.37/E^{0.5})$. This allows to decrease considerably an activation of the elements with small I_o/σ_o ratio (Na, K, Ca, Cr, Fe, Zn, La, Ce et al.) without practical decrease, in this case, of activation of many elements with high I_o/σ_o ratio, because their effective resonance energies lay higher than 10 eV, where Gd absorbtion is already small.

In table 5 the data on Ir and Re originating from the Monchegorsk nickel melting plant are presented. It is also well illustrated by table 7, which examplifies the data on the atmospheric transfer of Ni, Co, Sb, Ag, and Ir from the same plant. In this table the data on the concentration of these elements in the Tver District are shown.

The analysis of moss samples used to study changes in atmospheric deposition of metals around an iron complex in Northern Norway between 1898 and 1993 years resulted in determination of 38 elements, including most heavy metals known to be released to the air from this kind of industry. It was shown that the metal deposition pattern at and around the industrial complex has changed considerably during the above-mentioned period. Cromium deposition in the vicinity of the smelter increased by about a factor of 100, for example, that is a matter of great concern since Cr is known to be an element toxic to man.

In fig. 8 the results on the determination of trace elements distributions are presented as an example of INAA application in geology (determination of the trace and RE elements versus the depth of an oil well). It was shown in this work that there are three forms of trace elements distributions along an oil well.

As an example of the INAA application in geology, these and other diagrams were obtained by studying the element distribution, including rare-earths, along oil wells in one district of Cuba.

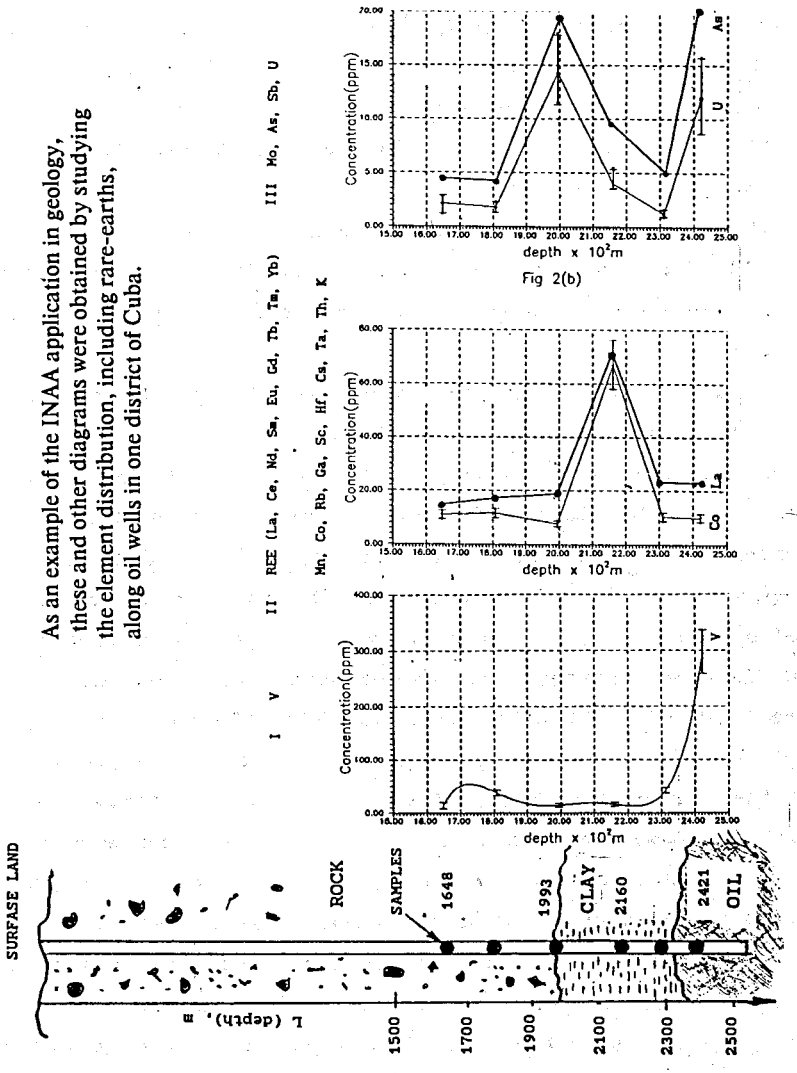

Fig. 8. Three forms of distributions for trace and RE elements along an oil well.

The first form is connected with V, which is being accumulated only in the oil layer. It is seen from the second form distribution that in the clay layer, disposed before the oil layer, the content of REE and also of K, Mn, Co, Rb, Ga, Sc, Hf, Cs, Ta, Th is 5-7 times higher. In the third form we have two peaks for Mo, As, Sb and U (the first one - before the clay layer and the second one in oil). These data are useful not only for the geochemistry of oil birthplaces, but also for the calibration of instruments for neutron carotage.

In determination of trace elements in high-purity materials the best results have been achieved by using the Ch3 and Ch4 channels. However, for high-purity Al more detailed results were obtained in the Ch3 (Gd coated) channel which is connected with a high content of Sc both in initial and in purified aluminium. As an example tables 8, 9 summarize results for one Al an ingot obtained by the method of zone melting. The ingot 70 cm length and 5 cm in diameter was used. The samples were taken consequently at the sites: 10, 60, 100, 200, 300, 400, 500, 600 and 700 mm from the begining of the fusion (pure) zone. The length, diameter and mass of the samples were 5 mm, 17 mm and 3 g, respectively.

Table 8 summarizes the values of both real concentrations (underlined) and detection limits only for the elements which were determined in the dirty zone of the ingot (initial Al) or in any part of the pure zone. The elements in the groups are arranged in the order of increase of their concentrations within the given interval. As is seen from table 8 the quality of the studied Al with respect to the admixtures content, is good. The degree of purification for many elements is very high, as it is seen from table 9. Here the degree of purification is the ratio of the element concentration in the dirty zone of the ingot to that in the pure zone (excluding Eu, Cr and Ta for which data were taken not for the dirty zone but for the initial Al).

Table 8. Element Concentrations for the Samples of High-Purity Aluminium

Interval of concentration (ppb)	Group of elements
10^{-2} - 10^{-1}	Lu Au
10^{-1} - 1.0	Cs Tb Eu Sm Sb Ta Th U
1.0 - 10	Hf Gd Co Ag Rb Ni Ce
10 - 100	Sn La Mo Nd W Sc
>100	Cr Zn Fe

Table 9. Summary of Power of Purification for High-Purity Aluminium

Power of purification of high-pure Al	Group of elements
10^3 - 10^4	Cs Lu
10^2 - 10^3	Ce Sm Th
10^1 - 10^2	Hf Ni U Au Nd La Gd Tb
1 -10	Sc Cr Ta W Rb Co Mo Ag Zn Eu Sn Sb Fe

As an example of the INAA application for studying water ecosystems some results of the investigations carried out in the Franz Josef Land can be presented/11/. Besides the above mentioned analysis of the lichens, the results of investigations of the trace elements distributions in snow, fresh snow, firn, melted water and water from tri lakes (waters from "Lunuij" glacier are trickling to one of them) are presented in this work.

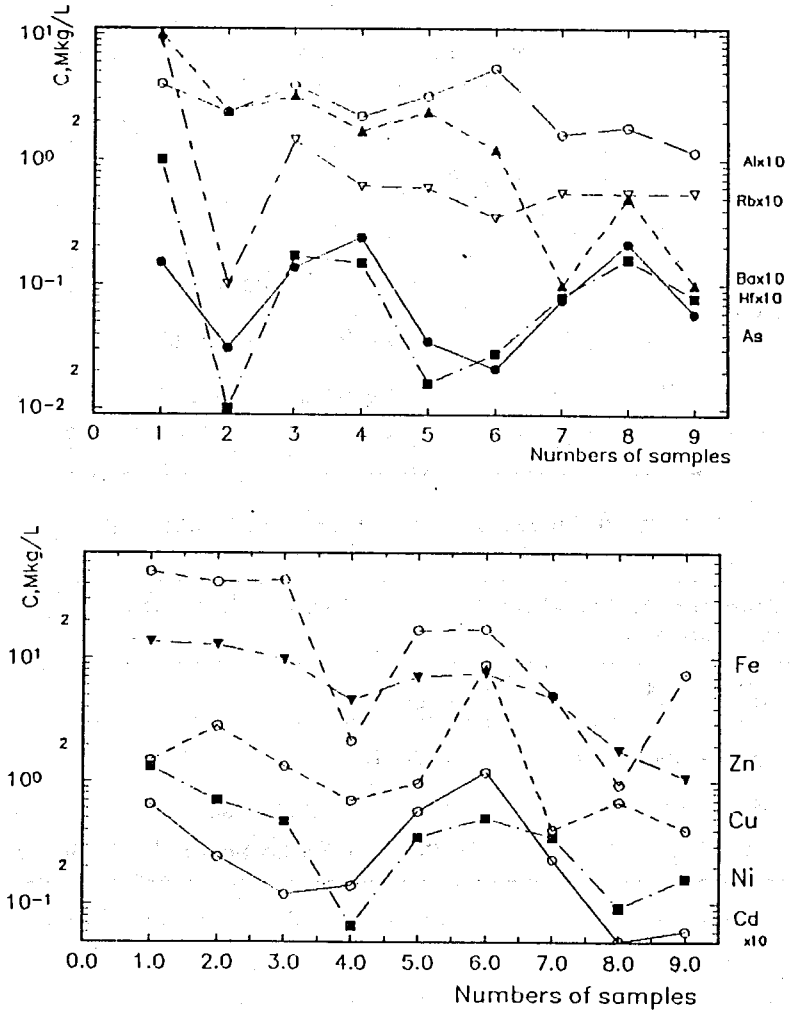

Fig. 9. Elements concentration of the soluble form in snow and water at the Franz Josef Land. 1 - unsoluble form (met. station), 2 - meteorologycal station, 3 - lake "Gel", 4 - fresh snow, 5 - snow (0-117 cm), 6 - firn (117-300 cm), 7 - melted water, 8 - lake "Glacier", 9 - lake "Glubokoe".

Thirty trace and macro elements were determined in these samples (Na, Mg, Al, Cl, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, Cu, As, Br, Rb, Sr, Zr, Ag, Cd, Sb, I, Ba, Hf, W, Au, Th, U).

For some trace elements fig. 9 presents interesting results. A significant accumulation of Cu, Ni, Cd, Fe and partially Zn in an averaged sample of firn (taken from the depth of 117 cm down to 300 cm) attracts attention in comparison with superficial snow and the waters of lakes. Otherwise the concentrations of such elements as Hf, As, Rb are significantly smaller than that in snow and the waters of lakes.

An increase of concentrations of all these elements (excluding As) in the region of meteostation does not need any explanation. It is clear that this is connected with the people activity.

Analogous trend is INAA application to the combined nuclear related and physical chemical methods in monitoring of aquatic ecosystems. These investigations were based on the data from the basin of the Oka river and were performed in collaboration with the Institute of the Lithosphere of ASR and at FLNP, Dubna. Results of the mapping obtained allow one to observe technogenic geochemical and biogeochemical anomalies in the given region.

Conclusions

We can see from above materials that the IBR-2 reactor, besides the main trends on the application in condenced matter physics, possesses large possibilities in the use of its beams and irradiation channels in different sciences and practical applications. It was shown above that the intensities and flux densities of the resonance neutrons allow one to use them for analysis of nearly 40 elements in different natural samples and in

environmental investigations. Satisfactory results on sensitivity of analysis at the IBR-2 reactor can be obtained in determination of trace elements in high-purity materials. Dynamic radiography with the use of the modern CCD TV camera opens new possibilities in investigations of the kinetics of defects in materials caused by an influence of high pressures and temperatures, and also in study of the fast processes of transfer of ions and their complexes in materials and in the model experiments with plants. As an example it is possible to study the fast processes of B and Cd transfer in plants in their stress conditions.

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