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**EXPERIMENTS ON CHEMISTRY  
OF ELEMENT 104—KURCHATOVIIUM**

**1. Development of a Method for Investigation  
of Short-Lived Isotopes**

ЛАБОРАТОРИЯ ЯДЕРНЫХ РЕАКЦИЙ

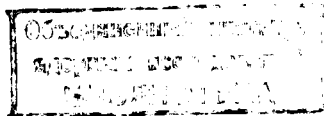
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## I n t r o d u c t i o n

The synthesis and studies of new transuranium elements are connected with ever increasing difficulties: the yield of nuclear processes used in synthesis sharply decreases<sup>/1-4/</sup> and the  $\alpha$  decay and spontaneous fission life-times of isotopes become too short<sup>/5,6/</sup>. The classical methods of coprecipitation, extraction and ion exchange in water solution cannot be used for investigation of chemical properties of new elements as they are too slow<sup>/7,8/</sup>. The short life-time and low yield of available isotopes of new elements involved require a highly effective continuous or quasi-continuous automatized technique for separation of the element from the mixture of target bombardment products and for withdrawal of its fraction for radioactivity measurement. The time from the moment of formation of an atom to the completion of an elementary experiment must be very short. Such processes would be very important as well for chemical identification, i.e. for determination of the atomic number of short-lived isotopes of known elements.

Under the above conditions the methods based on interactions in the gas phase and on the solid surfaces possess essential advantages. The use of gaseous compounds of the separated elements permits to obtain a higher speed of radiochemical separation. This has been realized only in simple cases: in studying short-lived isotopes of noble gases<sup>/9-10/</sup>, halogens<sup>/11/</sup> and elements forming volatile hydrides<sup>/12-14/</sup>.

The task of studying chemical properties of element 104 is one that may serve as an example of combined difficulties. This element was first obtained by G.N.Flerov and his co-workers<sup>/15/</sup>, who synthesized and identified its spontaneously fissioning isotope of 0.3 sec half-life by nuclear-physical methods. On the average one fission event was observed per 5 hours of operation of a heavy ion accelerator, used for synthesis.

The main chemical properties of the new element were to be compared with those of members of various groups of the Periodic Table in order to define its position in the Table from analogies and differences observed. According to the present ideas element 104 should be eka-

hafnium differing from the heavy transplutonium elements that were synthesized earlier and should be homologues of lanthanides<sup>7/</sup>. Therefore comparison of its properties with those of elements of subgroups IIIb and IVb was particularly important. But it should be mentioned that by the time of synthesis of element 104 no experimental data on properties of elements 102 and 103 had been available. In order to solve this problem we hoped to utilize one of the characteristic differences between elements of these subgroups: the markedly different volatility of their higher halides, particularly of chlorides. E.g. the vapour pressure of solid  $\text{HfCl}_4$  reaches 1 atm. at  $315^\circ$  while the boiling points of lanthanide trichlorides are higher than  $1500^\circ$ .

The scheme of the experimental arrangement selected for studying the chemical properties of element 104 is shown in Fig. 1. Nuclei of new element are yielded by interaction of accelerated  $^{22}\text{Ne}$  ions with  $^{242}\text{Pu}$  <sup>15/</sup>. With a sufficiently thin target the nuclear products of different simultaneous nuclear reactions will be emitted due to their recoil energy ( $\sim 10$  MeV). It was suggested to slow them down in the gas stream flowing continuously behind the target and to admit into the gas a chlorinating agent (e.g. chlorine) and a carrier for element 104 such as  $\text{ZrCl}_4$  or  $\text{HfCl}_4$  vapours. These compounds were expected to resemble its chloride. We supposed to choose such conditions under which the chlorides of the group III elements would be adsorbed to a great extent on the walls of the gas duct or on a special filter while  $(104)\text{Cl}_4$  would be transported without delay by the gas stream. The gas would pass then into the gap between the mica detectors for observation of fission fragments. Fragment tracks on the detectors would show that the atoms of element 104 have been chlorinated and its chloride has passed through the adsorption filter, thus giving evidence to certain chemical properties of the element. It was supposed that element 104 ekahafnium would be separated and thus distinguished from the group III elements as well as from other group elements forming non-volatile chlorides.

In order to prove that this experiment could be carried out we studied the behaviour of radioactive atoms of different elements (first of all of transition metals) in similar processes as a function of temperature,

nature of non-isotopic chloride carriers and chlorinating agents and the material the gas duct was made of. The effect of these factors on possible transporting of elements from target to detectors and on their velocity in passing this distance has been revealed. Conditions necessary for fast separation of hafnium from rare-earth elements (the simple model of experiment on chemistry of element 104) proved to be technically feasible.

## E x p e r i m e n t a l

Many experiments were performed directly in the apparatus designed for studies of element 104. The scheme of the gas duct used in experiments with long-lived  $\beta$  and  $\alpha$ -active isotopes of certain elements is shown in Fig. 2 (cf. Fig. 1).

Nuclear reactions induced by accelerated  $\text{O}$ ,  $\text{Ne}$  or  $\text{Ar}$  ions were used. Isotopes convenient for experimentation were obtained by selecting suitable targets and bombarding particles in reactions of type (heavy ion, xn ).

The  $10 \times 20$  mm target represented a layer of an element oxide  $1 \text{ mg/cm}^2$  thick deposited on the aluminium foil. This is comparable with the range of recoil atoms. These atoms were slowed down in a space of 11 mm deep. The gas was passed through this chamber under a pressure somewhat higher than the atmospheric one with a true flow rate of 30 l/min. The filter and the following parts of the gas duct were placed at a distance of 4 m from the target. The gas was passed through a tube of a 3 mm diameter, i.e. at the flow rate stated, in approximately 0.1 sec. The filter was loaded with the same material (ground), the tube was made of (teflon, glass, stainless steel IX18H9T), the inner surface of the filter being no larger than the inner surface of the tube. "Chemical filters"<sup>17/</sup> extracting the desired element due to chemical interaction or chemisorption and a trap for the condensate of the carrier vapour were located behind the filter in the place of mica detectors (Fig. 1). Complete trapping of isotopes in these two parts of the duct was checked in special experi-

ments. The whole gas duct except the carrier trap was heated. The experiments were carried out at 200° to 350°.

After continuous bombardment of the target for several hours necessary for obtaining atoms in an amount sufficient for recording the apparatus was dismantled and the distribution of the isotope in the different parts of the installation was studied. This gave the possibility of comparing the behaviour of various elements.

Experiments on adsorption of chlorides of microelements in the presence of chloride carriers were performed by a method developed earlier<sup>18/</sup> using a special apparatus that was not connected with the accelerator. A stream of nitrogen mixed with the carrier vapours and involving a certain constant partial pressure of the vapour of a labelled chloride is passed through the tube at a temperature falling down in the direction of gas motion. The substance is deposited on the tube walls due to adsorption or condensation and is distributed as a zone with a varying concentration per tube length unit. This distribution was determined radiometrically.

## Results and Discussion

### Efficiency of Transfer

The term "transfer efficiency"  $\eta$  refers to the portion of the total isotope amount having entered the gas stream which was transported to a given distance from the target along the duct in the course of the experiment of a certain duration<sup>19/</sup>. In this work the value  $\eta$  was determined by the amount of radioisotopes detected behind the filter i.e. on the chemical filter or in the carrier condensate trap upon 3- to 6 hours of bombardment (Fig. 1).

The transfer efficiency evidently depends on phenomena taking place under chemical interaction of atoms with the medium and during transportation of the products yielded along the gas duct.

The effect of some factors on  $\eta$  has been studied earlier. It was found that in the absence of chloride carriers, atoms of the studied ele-

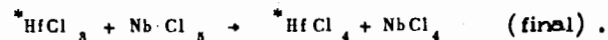
ments (Sc, Hf, Zr, Mo etc.) are mechanically swept by the gas stream (N<sub>2</sub>, Co<sub>2</sub>, Ar etc.) for a short distance along the tube with subsequent practically irreversible adsorption on its surface. There is also no transportation in a chlorine stream at temperatures up to 200°. But some elements start being transported upon introduction of vapours of chloride compounds (e.g. NbCl<sub>5</sub> - 0.2 mm of Hg). The transfer efficiency is determined mainly by selection of a carrier containing chlorine and the temperature range. The general trend consists in a decrease of the  $\eta$  value for the given element with lower temperature of the duct and in the presence of a more volatile carrier. The transfer efficiency is independent of the presence or absence of free chlorine. It does not even change if instead of slowing down the recoil atoms in the presence of a chloride carrier, the atoms previously stopped in pure inert gas are subjected to the action of carrier vapour<sup>16,17,19/</sup>.

This permits to draw a definite conclusion about the mechanism of processes affecting the possibility of transfer.

The chloride carrier vapours as such can act as chlorinating agents for recoil atoms and chlorination may be a strictly thermal process, requiring no excess energy of recoil atoms. A possible mechanism of chlorination involves several steps of the type :



and



A possibility is not excluded that more than one chlorine atom is turned over in one step. Due to a large excess of the chlorinating agent with respect to the microelement the chlorination will occur even when some of the reaction steps are not advantageous thermodynamically. Therefore the formation of molecules of a higher stable chloride might always be expected. The activation energies for such reactions involving radicals will be very low and thus the reactions will be fast. Formally these are reactions of the first order owing to ratios of reagent concentrations.

Under typical experimental conditions the mean chlorination time at any of the reaction steps should be  $\sim 10^{-2}$  sec at  $E_{act} = 10$  kcal/mole.

It follows that chlorination as such is not responsible for the transfer efficiency of microelement in the presence of chlorinating carriers.

Consequently the transfer efficiency is determined in the course of motion of molecules along the duct. It will be emphasized that the transportation regularities were studied as a rule at considerably lower temperature than the critical ones and even than the normal boiling points of the chlorides of the elements studied. This obviously requires discussing of adsorption phenomena.

Table 1 lists the results on transfer efficiency, obtained by using the apparatus designed for experiments with element 104. Unlike the general scheme in Fig. 1, in this apparatus the nuclei were slowed down in the stream of pure nitrogen and came into contact with the carrier at a distance of 30 mm from the target (Fig. 2).  $NbCl_5$ ,  $ZrCl_4$  and their mixture possessing necessary technological properties compared to pure  $ZrCl_4$  when used in prolonged experiments were investigated as carriers<sup>16/</sup>.

It may be seen from the Table 1 that only chlorides having a considerably higher boiling point than the carrier are not transferred in the presence of the carrier. For example indium behaviour shows that all more high-boiling chlorides are transferred effectively with temperature increasing.

A similar regularity was established in studying the effect of the carrier properties on the given microelement transfer: a high transfer efficiency may be obtained on condition that the carrier boiling point be higher than that of the element chloride or slightly below it. For example at  $200^\circ$  in a teflon apparatus  $^{97}Zr$  was not transferred with  $TiCl_4$  vapours (b.p.  $138^\circ$ ),  $SaCl_4$  ( $113^\circ$ ) and  $SeCl_4$  (subl.  $196^\circ$ ) but was transferred quantitatively with  $TaCl_5$  ( $232^\circ$ ),  $NbCl_5$  ( $246^\circ$ ) and  $ZrCl_4$  (subl.  $331^\circ$ ). At the same time  $^{101}Mo$  (b.p. of  $MoCl_5$  is  $268^\circ$ ) was appreciably transferred in the presence of  $TiCl_4$  or  $SaCl_4$ , and in the presence of  $TaCl_5$ ,  $MoCl_5$  or  $ZrCl_4$  there was quantitative transfer<sup>19/</sup>.

Thus there is a regular connection between transfer efficiency and

the volatility of microelement chloride and of the carrier. It will be seen below that the heat of vaporization rather than the boiling point is characteristic of the compound volatility. Its values are shown in Table 1.

An important conclusion made from data in Table 1 is the absence of an appreciable effect of the surface nature on the transfer efficiency when using a chloride carrier.

#### Action of Carriers

The role of the nonisotopic chloride carrier is believed to consist in the adsorption of the carrier with a consequent modification of the surface by saturation first the most active and then as well less active adsorption centers. The surface becomes more homogeneous. The heat of adsorption of the microcomponent on such a surface must become considerably lower and close to its heat of vaporization<sup>21/</sup> as condensation and adsorption processes are accounted for by the same forces. Experiment confirms that under such conditions the properties of the surface will not depend on the material used (cf. Table 1). They must be characterized by difference of the heat of adsorption value from the heat of vaporization of the microelement chloride, depending upon the carrier. When a volatile carrier is used that is adsorbed weakly and saturates only the most active surface centers the transfer efficiency will be less than with a higher boiling carrier. Some quantitative estimates were done earlier making use of the Langmuir isotherm<sup>19/</sup>.

The relative action of different carriers in suppressing the microcomponent adsorption is well illustrated by the results of investigation of  $^{95}Nb$  adsorption (probably  $NbCl_5$ ) in a tube with a temperature gradient. Fig. 3 shows the results of experiments using various carriers and chlorinating agents. Under the conditions used the high-temperature branch of the zone represents a peculiar "adsorption isobar" of the microcomponent. Its peculiarity is related to variations in the surface properties along the tube as the modifying action of carrier depends on temperature. When adsorption takes place in the condensation zone of the nonisotopic car-

rier the curve shape is affected also by such additional factors as the condensate surface area, decrease in the carrier vapour pressure, etc. The shape of the low-temperature branch of the zone is determined apparently by the kinetics of processes taking place (adsorption, diffusion in the gas).

It will be seen from Fig. 3 that beginning with the temperature of  $240^{\circ}$   $^{95}\text{Nb}$  is strongly adsorbed even at a great concentration of the highly volatile  $\text{SOCl}_2$  (b.p.  $75^{\circ}$ ),  $\text{TiCl}_4$  (b.p.  $138^{\circ}$ ) vapours in a much lower concentration displace the adsorption zone towards lower temperature. When an isotopic carrier is used  $^{95}\text{Nb}$  is trapped into the carrier condensate. In the presence of  $\text{ZrCl}_4$  vapours strong adsorption occurs at a temperature only below  $120^{\circ}$  i.e. far from the origin of the carrier condensation zone where the equilibrium vapour pressure of the carrier is about 0.01 mm of Hg.  $\text{Al}_2\text{Cl}_6$  also appeared to be a very effective carrier. This compound sublimates at  $180^{\circ}$  (cf.  $\text{TiCl}_4$ ) but its sublimation heat (27 kcal/mole) is close to that of  $\text{ZrCl}_4$  (25 kcal/mole) and apparently heats of vaporization are also close. It explains the equal action of these carriers.

All these results show that the high or on the contrary low efficiency of microelement transfer in the presence of certain carriers is not a consequence of any interaction peculiarity in the microelement - carrier combination under investigation. Suppressing the adsorption owing to the modifying action on the surface the carrier acts nonspecifically. As has been shown before it acts also as a nonspecific chlorinating agent. This is very important for substantiation of the method for studying a new element for which there is no isotopic carrier.

#### Transfer Time

The efficiency of transfer measured in prolonged experiments is only a rough characteristic of the microelement behaviour. It would be interesting to study in detail the correlation between the behaviour of the microelement and properties of its chloride. Some additional data have

been obtained in measuring the distribution in the tube and the filter of isotopes transferred with low efficiency. Their differentiation with respect to this index was found to be marked. For example, in a teflon wall duct at  $250^{\circ}$  more than 90% of the actinide and lanthanide isotopes are retained in the tube and only some per cent of total quantity reach the filter. Sc has been found in the tube and filter in comparable amounts and the  $^{137}\text{La}$  isotope was retained mainly by the filter. Again this is in accordance with the volatility of the chloride compounds of these elements (see Table 1).

These results indicate that all elements are capable of being transferred and the transfer efficiency is a function of the transfer time, which sometimes may be very long.

In principle transfer time  $t_t$  is a sum of two values. The first item is the time for chlorination of the atom to the higher chloride. The second one is the retention time -  $t_R$  which is a determining factor in gas chromatography. It is the mean overall time the molecule spends in the "column" in the moving gas stream or in immobile phase. In our case the gas duct is a kind of a chromatographic column and the separation procedure is something like frontal analysis. In the given equipment the molecule suffers about  $10^4$  collisions with solid surface when moving along the tube through the filter to the radiation detectors.

It has been established above that the time of chlorination seems to be very short and thus the transfer time should practically equal to the retention time.

The transfer time was measured and estimated by following three methods:

A) The procedure being similar to frontal chromatography the high transfer efficiency is obtained when the transfer time is considerably less than the experiment duration ( $t$ ). The absence of a considerable transfer means on the contrary that  $t_t > t$  (lanthanide and actinide elements). In the case of  $^{137}\text{La}$  and  $^{139}\text{La}$  partial transfer along the tube was observed in very long experiments ( $t = 30$  to  $70$  hours). The transfer increases with increasing  $t$ . It is better estimation of  $t_t$  from the velocity of the front motion.

B) Transfer time shorter than a second have been measured by a direct method making use of a short-pulse operation of the accelerator<sup>17/</sup>.

C) The basic relation in the theory of chromatographic separation relating the retention time of the substance in the column with the flow rate of the mobile phase (W) the column holdup (V) and the partition of the substance between the phases may be written here as

$$t_R = \frac{V}{W} \left( 1 + \frac{SN_s}{VN_v} \right),$$

where S is the column surface,  $N_s$  is an equilibrium quantity of molecules adsorbed on  $1 \text{ cm}^2$  at the molecular concentration in the gas phase  $N_v$  molecules/ $\text{cm}^3$ . The  $N_s$  and  $N_v$  values for different temperatures were evaluated from experimental data on adsorption of the substance from the gas phase in the tube with a temperature gradient (the high-temperature branch of the adsorption zone in Fig. 3).

All data on the transfer time are given in Table 2. Satisfactory agreement between the values for Hf obtained by different methods may be noted. It will be seen that there is an unambiguous correlation between the transfer time and the heat of vaporization of the element chloride (cf. Table 1).  $t_t$  depends strongly on the latter. For example, the transfer time of  $\text{TaCl}_5$  and  $\text{HfCl}_4$  that are relatively close with respect to their sublimation properties differs by more than three orders of magnitude. In this connection one peculiarity of the problem of short-lived isotopes separation in a frontal analysis type procedure will be emphasized (cf. Fig. 1): The condition of  $t_t > t$  is not necessary to prevent the isotope from reaching the detector. It is sufficient that the transfer time be so long as to ensure decay of the isotope when passing along the duct before it reaches the detector. The transfer efficiency for atoms of a given element determined in prolonged experiments with long-lived nuclides is always higher than the real value for a short-lived isotope of the element.

The considerable decrease  $t_t$  of Hf isotopes in the presence of  $\text{ZrCl}_4$  carrier compared to the value obtained in using  $\text{NbCl}_5$  alone will be noted. It shows the possibility of accurate control of  $t_t$  by using different carriers.

The transfer time of Hf isotopes in the presence of  $\text{ZrCl}_4$  in the experimental apparatus at  $250^\circ$  is not much longer than the half-life of element 104 and at  $300^\circ$  it becomes even less than the half-life. Thus these conditions seem to be suitable for experiments with ekahafnium. The transfer time for lanthanide and actinide isotopes is  $> 10^5$  times longer and this gives the possibility of a good separation of elements belonging to different groups. The transfer efficiency of lanthanides was measured many times in experiments of different duration and was found to be 1-2%. The corresponding separation factor of 50-100 may be higher for the short-lived isotopes as mentioned above. However, it is possible that 1 to 2% transfer occurs not by the usual adsorption-desorption mechanism of the molecule motion but is accounted, e.g. by adsorption of molecules on particles of finely-dispersed aerosols, the formation of which cannot be prevented beforehand.

The velocity of aerosol motion obeys other laws and may be higher than that of non-volatile chloride molecules and even close to the velocity of the stream. In the last case the decontamination factor determined for a long-lived isotopes will not increase for short-lived isotopes if their  $T_{1/2} > 0.1$  sec.

The conditions for fast transfer of ekahafnium that were chosen in experiments with hafnium are far from those for fast transfer of such elements as Th, rare-earth elements Cf, Fm, Na, Sc, etc. Thus the difference in the properties of element 104 and in those of the above elements may be proved by a rather simple experiment. The task of separating chlorides of the IVth, Vth and VIth groups that all are volatile and may be transferred under conditions favourable for ekahafnium because of the nonspecific action of carriers, may obtain solution<sup>17/</sup> by complicating the experiment scheme. For example, it has been shown<sup>17/</sup> that a filter of KCl adsorbs the IVth group elements from the gas stream while the Vth group elements pass through such a filter without hindrance.

All these results permitted to start experiments with element 104 and give possibility to develop other radiochemical separation techniques based on the above discussed phenomena.



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Table 1  
Transfer Efficiency of Various Isotopes with ZrCl<sub>4</sub> and NbCl<sub>5</sub>  
Vapours  
NT - no transfer ( $\eta < 5\%$ ); T - quantitative transfer

Nuclide	Temperature								Probable Boil. state	Heat of vapor. (kcal/mole)				
	250°				300°									
	Carrier (mm of Hg)													
	NbCl <sub>5</sub> (0.2)	ZrCl <sub>4</sub> (0.1)	NbCl <sub>5</sub> (0.15) +ZrCl <sub>4</sub> (0.05)	NbCl <sub>5</sub> (0.2)	NbCl <sub>5</sub> (0.15) +ZrCl <sub>4</sub> (0.05)	Material of tube <sup>a</sup>		point (°C)						
ss	tfl	ss	tfl	ss	tfl	ss	gl	ss	gl					
<sup>256</sup> <sub>102</sub> <sup>b</sup>	-	NT	-	-	-	-	-	-	NT	-	NT	(102)Cl <sub>3</sub>	-	-
<sup>252</sup> Fm	-	NT	-	-	-	-	-	-	NT	-	NT	FmCl <sub>3</sub>	-	-
<sup>246</sup> Cf	-	NT	-	-	-	NT	-	-	NT	-	NT	CfCl <sub>3</sub>	-	-
<sup>240</sup> Cm	-	-	-	-	-	NT	-	-	-	-	NT	CmCl <sub>3</sub>	(1700)	-
<sup>157</sup> Dy	-	NT	-	-	-	NT	-	-	NT	-	NT	DyCl <sub>3</sub>	1530	58 <sup>c</sup>
<sup>149</sup> Tb	-	NT	-	-	-	NT	-	-	NT	-	NT	TbCl <sub>3</sub>	1550	59 <sup>c</sup>
<sup>148</sup> Gd	-	NT	-	-	-	-	-	-	-	-	NT	GdCl <sub>3</sub>	1580	59 <sup>c</sup>
Ce	NT	-	NT	-	-	-	-	-	-	-	-	CeCl <sub>3</sub>	1700	64 <sup>c</sup>
<sup>44</sup> Sc	NT	NT	NT	-	NT	NT	NT	NT	NT	NT	NT	ScCl <sub>3</sub>	s.967	46
<sup>24</sup> Na	NT	NT	NT	-	NT	NT	NT	NT	NT	NT	NT	NaCl	1465	41 <sup>c</sup>
<sup>109</sup> In	-	NT	-	-	-	NT	-	T	-	-	T	InCl <sub>3</sub>	s.498	(30)
<sup>170</sup> Hf	T	T	T	-	T	T	T	T	T	T	T	HfCl <sub>4</sub>	s.316	(16)
<sup>86,87</sup> Nb	-	T	-	T	-	-	-	-	-	-	-	NbCl <sub>5</sub>	246	12
<sup>48</sup> V	T	-	-	-	-	-	-	-	-	-	-	VCl <sub>4</sub>	164	8,2
<sup>110</sup> Sn	T	T	-	-	-	-	-	-	-	-	-	SnCl <sub>4</sub>	113	8,3

<sup>a</sup> stainless steel, teflon, glass    <sup>b</sup> cf. paper (20)    <sup>c</sup> at melt.point (~800°)

Table 2  
Transfer Time of Some Isotopes (seconds)

Nuclide	Carrier (mm of Hg)	Temperature		Method of $t_t$ determ.
		250° teflon	300° glass	
$^{252}\text{Fm}$	$\text{NbCl}_5(0.2)$	$\gg 2 \cdot 10^5$	$\gg 2 \cdot 10^5$	A
$^{246}\text{Cf}$	$\text{NbCl}_5(0.15) +$ $+\text{ZrCl}_4(0.05)$	$\gg 2 \cdot 10^5$	$\gg 2 \cdot 10^5$	A
$^{149}\text{Tb}$				
$^{44\text{m}}\text{Sc}$	$\text{NbCl}_5(0.15) +$ $+\text{ZrCl}_4(0.05)$	$\sim 2 \cdot 10^5$	$2 \cdot 10^5$	A
$^{24}\text{Na}$	$\text{NbCl}_5(0.15) +$ $\text{ZrCl}_4(0.05)$	$1 \cdot 10^5$	$3 \cdot 10^4$	A
$^{234}\text{Th}$	$\text{ZrCl}_4(2.0)$	$1 \cdot 10^5$	$10^4$	C*
$^{109}\text{In}$	$\text{NbCl}_5(0.15) +$ $+\text{ZrCl}_4(0.05)$	$10^4$	$1 < t_t < 10^3$	A
$^{170,171}\text{Hf}$	$\text{NbCl}_5(0.2)$	1.0	0.5	B
	$\text{NbCl}_5(0.15) +$ $+\text{ZrCl}_4(0.05)$	0.4	0.2	B
$^{181}\text{Hf}$	$\text{NbCl}_5(2.5)$	0.5	0.2	C*
$^{95}\text{Nb}$	$\text{SOCl}_2(80)$	1.3	0.3	C*
	$\text{ZrCl}_4(0.5)$	$\sim 0.1$	0.1	C*

\*Assuming  $t_t = t_R$

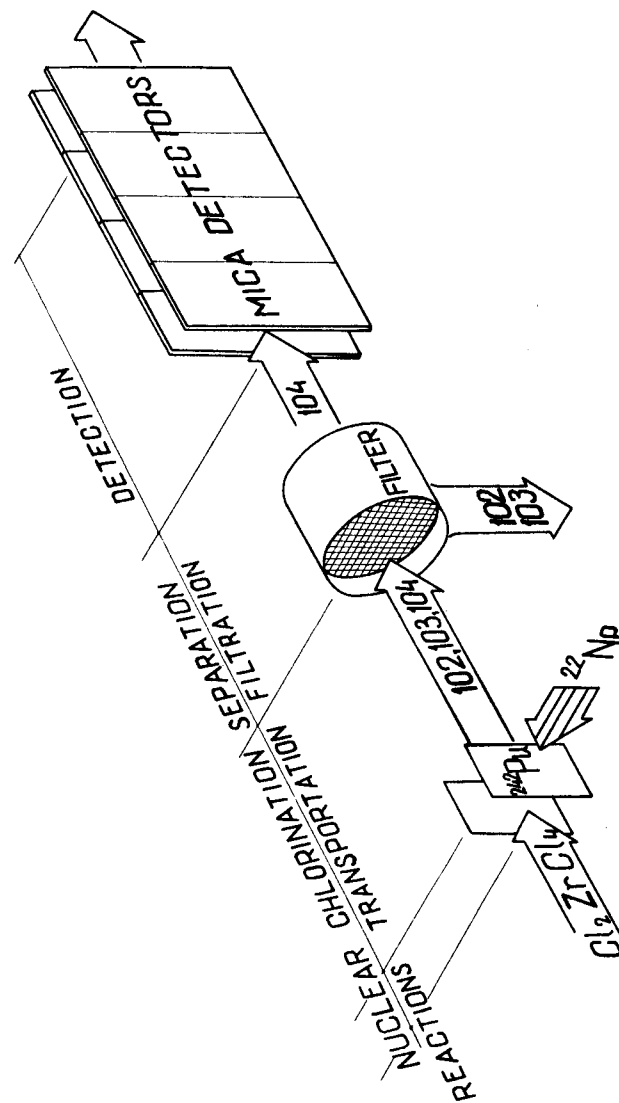


Fig. 1. Proposed scheme of an experiment for investigation of chemical properties of element 104 short-lived isotope.

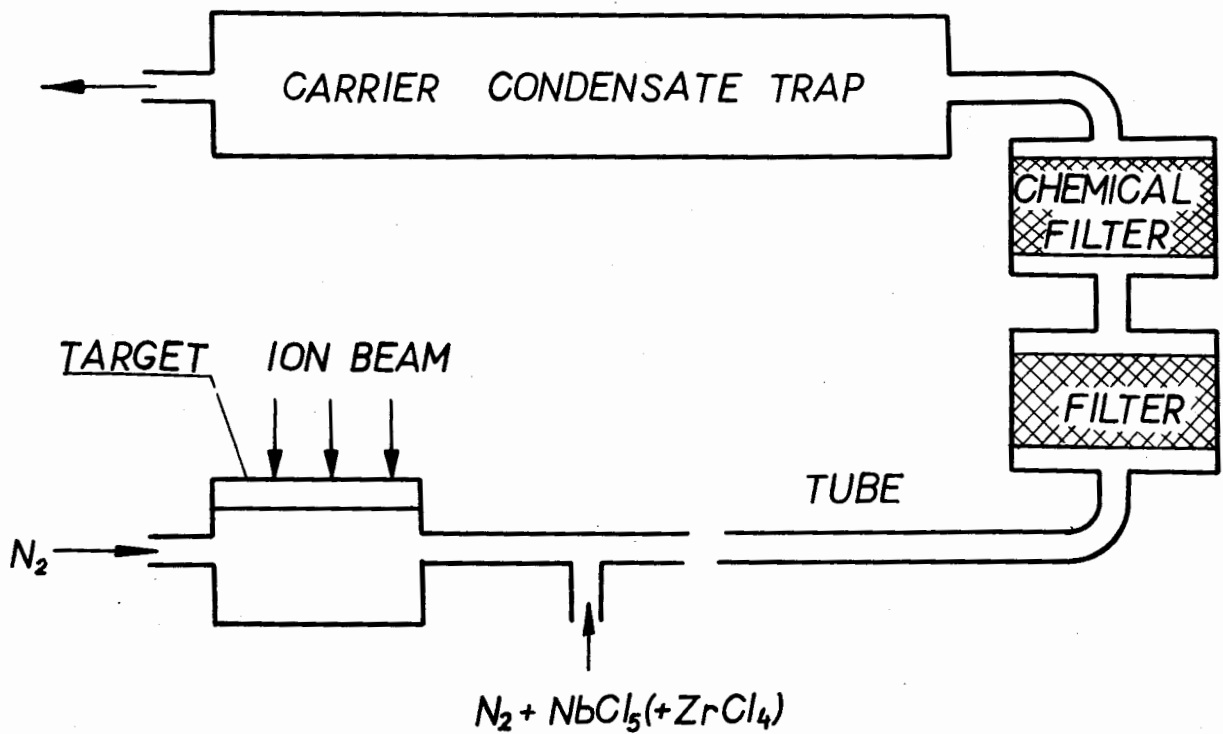


Fig. 2. Block diagram of the gas duct of the apparatus.

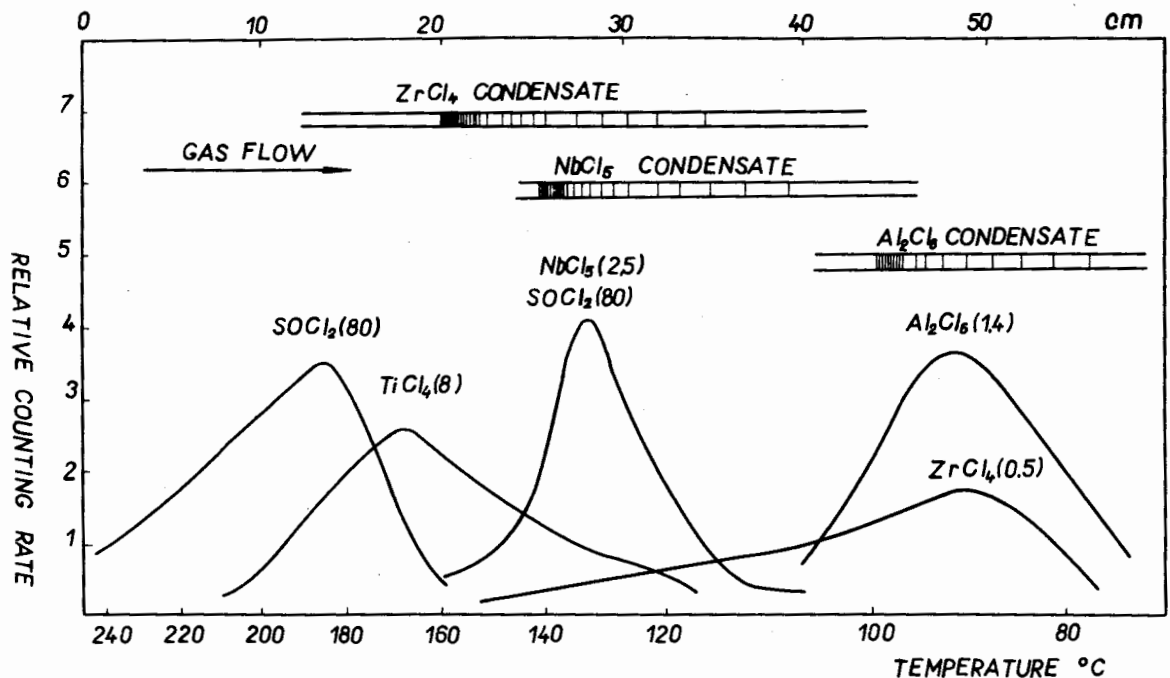


Fig. 3. The adsorption of trace amounts of  $^{95}\text{Nb}$  from the gas phase containing various chloride carriers in a tube with temperature gradient maintained.

Experimental conditions: Inert gas - nitrogen at atmospheric pressure with flow rate of  $26 \text{ cm}^3/\text{min}$  (at STP). The duration of an experiment was 10 min. Pyrex tube with 7 mm i.d. was used. The initial carrier partial vapour pressure in mm of Hg is given in brackets after formulas.  $5 \mu\text{c}$  of  $^{95}\text{Nb}$  "without carrier" was taken for each experiment and its distribution was measured by  $\gamma$  activity through a 10 mm clearance.