Physics – Uspekhi **67** (7) 717 – 744 (2024)

FROM THE HISTORY OF PHYSICS PACS number: **01.65.+g**

Employees of the Institute of Metal Physics of the Ural Branch of the Russian Academy of Sciences and the development of the Soviet Atomic Project

S A Gudin

DOI: https://doi.org/10.3367/UFNe.2024.02.039648

Contents

Abstract. The paper highlights the contribution of the employees of the Institute of Metal Physics of the Ural Branch of the Russian Academy of Sciences to the first stage of the USSR Atomic Project. The main challenge of the project was the need to solve one of the most difficult problems that the developers of the USSR atomic shield faced — industrial separation of uranium isotopes. Thus, in 1943, I K Kikoin directed the first work on isotope separation using diffusion and centrifuge methods at the institute. I K Kikoin was appointed I V Kurchatov's deputy and was the main person responsible for the development of an industrial method for producing uranium-235 isotopes.

S A Gudin. M N Mikheev Institute of Metal Physics of Ural Branch of Russian Academy of Sciences, ul. S Kovalevskoi 18, 620108 Ekaterinburg, Russian Federation
E-mail: gudin@imp.uran.ru

Received 16 September 2023, revised 14 February 2024
Uspekhi Fizicheskikh Nauk **194** (7) 765 – 789 (2024)
Translated by I A Ulitkin

Keywords: USSR Atomic Project, industrial separation of uranium isotopes, isotope separation by gaseous diffusion, isotope separation by centrifuge methods, uranium-235, Ural Physico-Technical Institute (UralFTI), counterflow centrifuges

...Perhaps more than any other group in the project, those who have worked on gaseous diffusion deserve credit for courage and persistence as well as scientific and technical ability...
Smith H D *Atomic Energy for Military Purposes: Official Report on the Development of the Atomic Bomb Under the Auspices of the United States Government, 1940–1945*
(Princeton, New Jersey: Princeton University Press, 1945)

1. Introduction

Henry Smith — the author of the Manhattan Project report, whose words are quoted as an epigraph to this paper — emphasizes the complexity of the task of separating uranium isotopes and singles it out among the huge number of challenging problems solved during the creation of atomic

weapons. The Soviet Union lagged several years behind the USA and Great Britain in work on the Atomic Project. In the USSR, scientists from the Institute of Metal Physics of the Ural Branch of the Russian Academy of Sciences (IPM UB RAS; hereinafter referred to, for brevity, as the IPM) in Ekaterinburg took direct part in solving the problem of separating uranium isotopes.

The present paper highlights the contribution of the IPM research fellows who participated in the work on the first stage of the Soviet Atomic Project. This contribution is little known, mainly due to the transfer of those recruited to the Atomic Project to work in such specially established institutions as Laboratory No. 2 of the USSR Academy of Sciences, the Ural Electrochemical Combine (Novouralsk), and KB-11 (RFNC-VNIIEF, Sarov). Thus, history could have taken a different path. This is how Isaak Konstantinovich Kikoin, I V Kurchatov's deputy, recalls things: *I proposed to organize all the work in Sverdlovsk, where I had a good laboratory, and where there was also an institute of physics that could be used as well. All this was in a big industrial city, away from the front lines and with a power plant and a qualified workforce. But my proposal was rejected, since the uranium problem was considered problem number one, and the government, which fully appreciated the vital necessity to solve this problem, was directly interested in its fastest completion. Therefore, it was decided to build the institute, or Laboratory No. 2* (*as it was coded*)*, in Moscow, so that no purely formal issues regarding the resolution of certain questions would slow down the already difficult progress of the work* [1, p. 34].

I K Kikoin with his wife V N Tyushevskaya and daughter Lyuba at a demonstration (1940s).

2. Beginning of Atomic Project

On September 28, 1942, the USSR State Defense Committee adopted classified decree GKO No.2352ss on the Organization of Work on Uranium [2], and in mid-October 1942, I V Kurchatov was summoned to Moscow, where S V Kaftanov, an authorized representative of the State Defense Committee, informed him that "the government had decided to resume and widely expand work on the uranium problem" [3]. On February 11, 1943, a new decree of the State Defense Committee was adopted, according to which Igor Vasil'evich Kurchatov was appointed scientific director of work on the 'uranium problem.'

At the end of 1942, I V Kurchatov visited the laboratory of I K Kikoin in Sverdlovsk and, apparently, was satisfied with the quality and quantity of work and their connection with industry, and soon Isaak Konstantinovich, as Kurchatov's deputy, was involved in the work on developing an industrial method for separating uranium isotopes in order to obtain uranium-235.

In early 1943, I K Kikoin was transferred to Moscow. On September 29, 1943, the USSR Academy of Sciences elected I K Kikoin a corresponding member of the USSR Academy of Sciences, and I V Kurchatov became a full member of the USSR Academy of Sciences. Kikoin was appointed scientific director of one of the research areas of the uranium project — the separation of uranium isotopes in order to obtain the uranium-235 isotope. I K Kikoin wrote: *Quite soon we, that is, I V Kurchatov and I, divided 'the spheres of influence.' Igor Vasil'evich was a great specialist in nuclear physics. I took on solving the problem of separating uranium isotopes, that is, obtaining the fissionable material necessary for producing an atomic bomb...* [4, p. 6]. The part related to I V Kurchatov's sphere of influence has been studied quite well to date [5–17], and therefore this paper is devoted to I K Kikoin's sphere of influence.

At the first stage, many researchers from the IMP UB RAS were involved in the Atomic Project. I was able to find the names of 17 people: I K Kikoin, V S Obukhov, D L Simonenko, M V Yakutovich, S V Karpachev, I N Polyakov, P A Khalileev, S K Sidorov, A P Komar, D M Tarasov, N N Buinov, V S Averkiev, L V Bulanaya, V N Tyushevskaya,

and A K Kikoin, as well as Bardin and Korsunskii, whose initials, unfortunately, I failed to establish.*

Who were these people, why were they involved in the Atomic Project, and had they been involved in atomic research before? The IPM UB RAS was founded in 1932 on the basis of a group of scientists from the Leningrad Physicotechnical Institute; hence, the first name was the Ural Physico-Technical Institute, where I K Kikoin headed the Laboratory of Electrical Phenomena.

In 1942, I K Kikoin, S V Gubar, and V S Obukhov published a paper entitled "A new system of electrical measuring equipment for measuring high-intensity direct currents" [18]. That same year, they were awarded the Stalin Prize of the third degree for the work described in their paper, with the wording "for the invention of a new system of electrical measurements on high-intensity direct currents." Thus, scientists the at Institute of Metal Physics were honored with the first State Prize. What was so interesting and important about this development? Let us turn to the memoirs of I K Kikoin [19, p. 583]: *...comrades from Kamensk-Uralsk came to my laboratory and introduced themselves as employees of an aluminum plant*; *they said that their plant had been built, but its launch was delayed because they could not make adjustments to the electrolysis baths*; *this was done by eye, since there was no way to control huge currents of several ten thousand amperes flowing through the baths, and so the baths either were burnt or frozen.*

— Could you help us?

— I personally have never dealt with such issues, but we can try.

Together with my fellow workers, I went to the plant to see what the matter was and whether there was any way to help. We were shown a brand new bath through which a current of 50,000 amperes should flow. The conductors were huge aluminum boards, and, of course, it was unknown how to measure such a current. But the problem had been formulated and had to be solved. This is where my accumulated experience and knowledge came in handy. I realized that there could be no direct measurement of the current, but the magnetic field directly near the conductor through which the current flows depends on this current, and therefore I decided to replace the direct measurement of the current with the measurement of the magnetic field of the conductor. The necessary experiments were performed immediately right in the workshop. Having returned from the plant, we began to design the device. Soon a necessary device was developed, which we tested at the plant. It turned out that it meets absolutely all the conditions and allows the current to be measured with the specified accuracy or even better.

A series of devices was immediately fabricated, which we took to the plant. Together with the plant workers, we assembled them, tested them and began debugging the bath. The baths worked normally, and the first metal was soon produced. The first ingots were cast. As a very special reward, we were presented with souvenir ingots from this first aluminum of the Kamensk-Uralsk plant. Of course, the first ingot was sent to Stalin, the second was delivered to the regional committee secretary, and the third was given to me as a souvenir of the plant's launch. I will cite excerpts from the paper entitled "A new system of electrical measuring equipment for measuring high-intensity direct currents" [18]. The paper was published in 1942 and explained the difficulties in using the traditional approach, that is, the shunt method of current measurement: *Such shunts, designed for currents on the order of several ten thousand amperes, are very bulky structures. For example, a* 10,000-A *shunt weighs about 35 kg* (*the weight of a shunt*[1] *grows proportionally to the square of the current*). *...In the USSR, shunts for currents above* 5000 A *have been imported up to now. But abroad, shunts were also manufactured for currents no higher than* 30,000 A, *while at a number of our plants, currents reach* 70,000 A *or higher. Manufacturing shunts for high currents runs into fundamental difficulties. It is difficult to obtain a casting of a homogeneous alloy.*

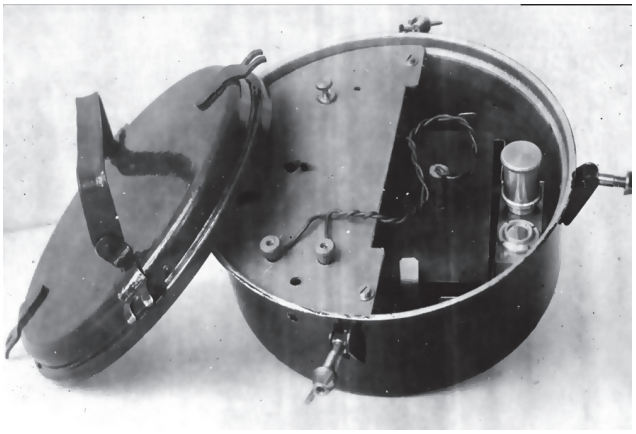
I K Kikoin, S V Gubar, and V S Obukhov developed, designed, and fabricated the following devices that made it possible to take measurements at currents up to 70,000 A: portable kiloammeters (for measuring the distribution of currents across the anodes of electrolytic baths), stationary kiloammeters (for measuring the current in the main circuit with the transmission of readings to the control panel), workshop kiloammeters with a large scale of a diameter up to 800 mm, kilowatt-hour meters, and ampere-hour meters. During the war, I K Kikoin's laboratory equipped many Ural factories with these devices. Contacts with the factories continued to be maintained. In the character reference of V S Obukhov of November 15, 1942 [20], I K Kikoin writes: *With his participation, equipment for automatic control of hardening of products in electric furnaces was developed. Moreover, in his latest work, he developed a very original design of a contact mechanism. At present, Comrade Obukhov is participating in a number of defense projects carried out in the laboratory. Some of them are being successfully completed. All of V S Obukhov's work bears the stamp of great initiative and independence. Since 1942, V S Obukhov has been a laureate of the Stalin Prize. Therefore, I consider it absolutely correct and extremely desirable to award Comrade Obukhov the title of senior research fellow.* The proposal of the Presidium of the Ural Branch of the USSR Academy of Sciences to award the academic title of senior research fellow to V S Obukhov was

* When the Russian version of the paper had already been published, one of the veterans of the Institute of Metal Physics, Doctor of Physics and Mathematics Vitalii Il'ich Zel'dovich, who read it, informed us of Korsunskii's first and middle names, and provided some information about him: *I know Korsunskii's initials. His full name was Moisei* (*Mikhail*) *Izrailevich Korsunskii, and he was the author of the popular book* The Atomic Nucleus (*Moscow, 1949*). *He read us* (*students in the Engineering Physics Department at the Order of Lenin Kharkov Polytechnic Institute*) *lectures on Experimental Physics, and his assistant demonstrated experiments.* I would like to take this opportunity to sincerely thank V I Zel'dovich for the information he provided, which allowed us to find articles about M I Korsunskii published in *Physics–Uspekhi* [84–86]. Little is known about Moisei Izrailevich in the period from 1943 to 1945; it is only known that he took part in the Atomic Project. It is quite possible that when Lange was assigned to the Institute of Metal Physics, the same happened to Korsunskii, who before the Great Patriotic War had headed the Shock Voltage Laboratory (SVL) in Kharkov (F Lange was the scientific director of the laboratory). In his report to I V Kurchatov on the results of the trip to Sverdlovsk and the state of work on the centrifuge and diffusion machine as of September 21, 1943 [46], I K Kikoin mentioned Korsunskii. Later, Korsunskii was sent to Kharkov, and so the letter from L P Beria to I V Stalin of November 1946 [87, p. 664] states that M I Korsunskii during these years was involved in the same topics as I K Kikoin: *The department 'M' organized as part of the Physicotechnical Institute of the Academy of Sciences of the Ukrainian SSR had the task to conduct research under the supervision of Professor Korsunskii on the separation of uranium isotopes by the molecular magnetic method.* Unfortunately, we have failed to find Bardin's full name. Perhaps one of our readers will be able to help us. (*Author's note to English proof.*)

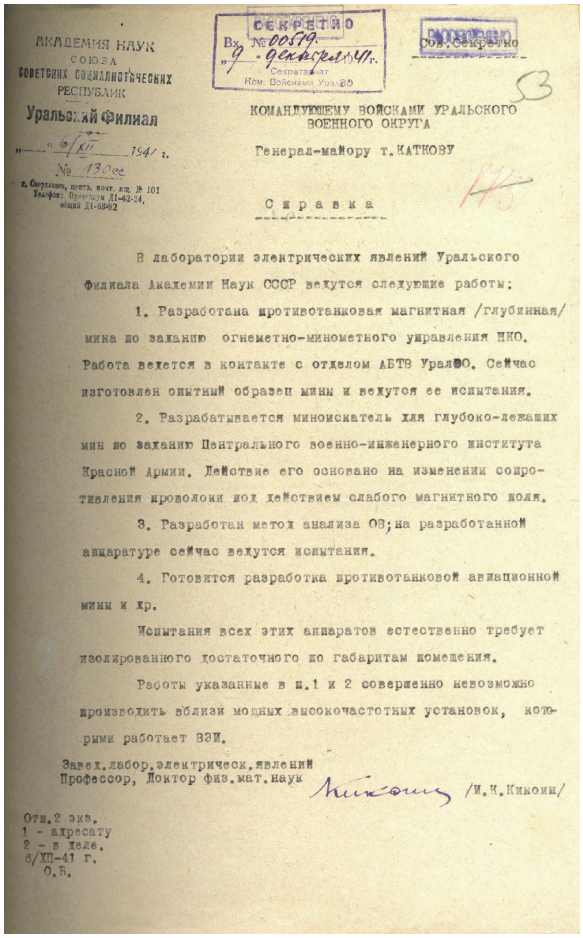
[1] Based on this information, a 70,000-A shunt should weigh about 1700 kg.

rejected at a meeting of the Presidium on September 2, 1943 (speaker Secretary of the Presidium of the USSR Academy of Sciences, Academician N G Bruevich) [21], "as not having the academic degree of candidate of sciences." The personal file of V S Obukhov contains a petition from N V Demenev — assistant to the chair of the Ural Branch of the USSR Academy of Sciences for scientific affairs, director of the Institute of Metal Physics and Metallurgy (another former name of the IPM UB RAS) — to the Committee for Higher School Affairs under the Council of People's Commissars of the USSR dated June 16, 1943: *Considering the long and successful scientific work of Stalin Prize Laureate V S Obukhov, I ask that he be allowed to defend his candidate's dissertation without passing candidate's exams* [22]. The question arises as to why such a seemingly simple matter as passing candidate's exams was considered at the highest level. In Sverdlovsk, there was no dissertation council at that time and, in order to pass these exams, it was necessary to go to Moscow. With the war going on, Obukhov was already involved in intense work related to solving defense problems.

By December 1941, on the orders of the People's Commissariat of Mortar Armament, an anti-tank magnetic mine (deeply buried) had been developed. In the Report to the Commander of the Troops of the Ural Military District, Major General A V Katkov, dated December 6, 1941 [23, p. 252], I K Kikoin wrote: "A prototype of the mine has now been manufactured and is being tested. ...The development of an anti-tank aviation mine, etc., is being prepared." V S Averkiev recalls, *We were developing a design for a portable mine for partisans. The requirements were very strict*: *small size and weight, airtightness* (*so that the mines could be left in a swamp and they would not deteriorate for several days*); *it was also necessary that the mines not explode from detonation. Several people worked on it, including I K Kikoin, V S Obukhov, and V S Averkiev*; *they worked very enthusias-*



Deeply buried anti-tank mine designed by I K Kikoin, V S Obukhov, and V S Averkiev.



АКАДЕМИЯ НАУК СОЮЗА СОВЕТСКИХ СОЦИАЛИСТИЧЕСКИХ РЕСПУБЛИК
Уральский Филиал
"6" XII 1941 г.
№ 130сс
г. Свердловск, почт. ящ. № 101
Телефон: Приемная Д1-42-24, общий Д1-68-82

СЕКРЕТНО
Вх. № 00519
"9" декабря 1941 г.
Секретариат
Ком. Войсками Урало-ВО

КОМАНДУЮЩЕМУ ВОЙСКАМИ УРАЛЬСКОГО ВОЕННОГО ОКРУГА
Генерал-майору т. КАТКОВУ

Справка

В лаборатории электрических явлений Уральского Филиала Академии Наук СССР ведутся следующие работы:

1. Разработана противотанковая магнитная /глубинная/ мина по заданию огнеметно-минометного управления НКО. Работа ведется в контакте с отделом АБТВ УралВО. Сейчас изготовлен опытный образец мины и ведутся ее испытания.

2. Разрабатывается миноискатель для глубоко-лежащих мин по заданию Центрального военно-инженерного института Красной Армии. Действие его основано на изменении сопротивления проволоки под действием слабого магнитного поля.

3. Разработан метод анализа ОВ; на разработанной аппаратуре сейчас ведутся испытания.

4. Готовится разработка противотанковой авиационной мины и пр.

Испытания всех этих аппаратов естественно требует изолированного достаточного по габаритам помещения.

Работы указанные в п.1 и 2 совершенно невозможно производить вблизи мощных высокочастотных установок, которыми работает ВЭИ.

Завед. лабор. электрическ. явлений
Профессор, Доктор физ.-мат. наук /И.К.Кикоин/

Отп. 2 экз.
1 – адресату
2 – в дело.
6/XII-41 г.
О.В.

Academy of Sciences
of the Soviet Socialist
Republics Ural branch
December 6, 1941
No. 130ss Sverdlovsk,
central post
box No. 101
Telephone:
Presidium—D1-42-24,
general—D1-68-82

Classified
Registration No. 00519
December 9, 1941
Secretariat of the troops
of the Ural military district

TO THE COMMANDER OF THE TROOPS
OF THE URAL MILITARY DISTRICT
Major General Comrade KATKOV

Reference

The following work is being carried out at the Laboratory of Electrical Phenomena of the Ural Branch of the USSR Academy of Sciences:

1. An anti-tank magnetic /deeply buried/ mine has been developed on the instructions of the Mortar Armament Department of the People's Commissariat of Defense.

— The work is being carried out in contact with the Armored Troops Department of the Ural Military District. An experimental model of the mine has now been manufactured and is being tested.

2. A mine detector for deeply buried mines is being developed on the instructions of the Central Military Engineering Institute of the Red Army. Its operation is based on a change in the resistance of the wire under the influence of a weak magnetic field.

3. A method for analyzing toxic agents has been developed; tests are currently being carried out on the developed equipment.

4. Development of an anti-tank air mine, etc., is in preparation.

Testing all these devices naturally requires an isolated room of sufficient size.

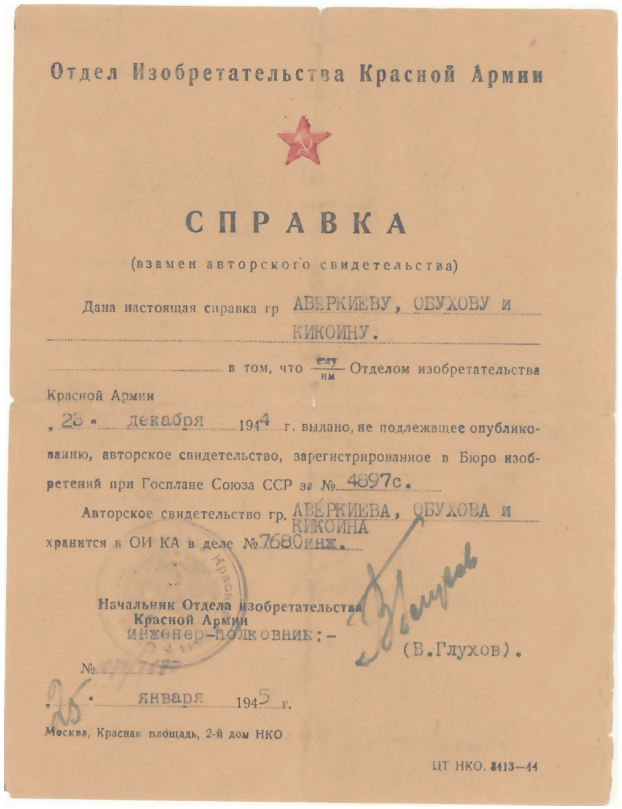
The work specified in paragraphs 1 and 2 is absolutely impossible to carry out near the high-power, high-frequency installations that VEI operates.

Head of the Laboratory of Electrical Phenomena,
Professor, Doctor of Physical and Mathematical Sciences

/I K Kikoin/

2 copies printed
1 — to the addressee
2 — in the file December 6, 1941 O.B.

I K Kikoin's certificate for developments at Laboratory of Electrical Phenomena, dated December 6, 1941 (TsDOOSO F_4_op_31_D_197_L_53OTs_02_4_31_197_53).



Отдел Изобретательства Красной Армии

СПРАВКА

(взамен авторского свидетельства)

Дана настоящая справка гр АВЕРКИЕВУ, ОБУХОВУ и КИКОИНУ.

в том, что Отделом изобретательства Красной Армии

„25" декабря 1944 г. выдано, не подлежащее опубликованию, авторское свидетельство, зарегистрированное в Бюро изобретений при Госплане Союза ССР за № 4897с.

Авторское свидетельство гр. АВЕРКИЕВА, ОБУХОВА и КИКОИНА хранится в ОИ КА в деле № 7680инж.

Начальник Отдела изобретательства Красной Армии
инженер-полковник: — (В.Глухов).

№

„25" января 1945 г.

Москва, Красная площадь, 2-й дом НКО

ЦТ НКО. 8413—44

Red Army Invention Department

REFERENCE
(in lieu of author's certificate)

This reference is given to citizens Averkiev, Obukhov, and Kikoin stating that, on December 23, 1944, the Red Army Invention Department issued them an author's certificate, not subject to publication, registered in the Bureau of Inventions under the State Planning Committee of the USSR under No. 4897s.

The author's certificate of citizens Averkiev, Obukhov, and Kikoin is kept in the Red Army Invention Department in file No. 7680inzh.

Head of the Red Army Invention Department, Colonel-Engineer:

(V Glukhov)

January 25, 1945
Moscow, Red Square,
2nd Department of the Office
of the People's Commissariat of Defense

Reference (in lieu of author's certificate) to I K Kikoin, V S Obukhov, and V S Averkiev of January 25, 1945.

tically. The basis of the design was a magnetic needle rotating in a vertical plane. In the normal state, it was located horizontally, but if something iron was above the mine, the needle deflected upward and closed the contact. Aluminum soldier's mess tins with a screw-on lid were used as housings. The mines were manufactured and passed tests quite successfully [23, p. 250]. On December 23, 1944, I K Kikoin, V S Obukhov, and V S Averkiev were issued inventor's certificate No. 4897c for a "Deeply buried anti-tank mine" [23, p. 253].

As can be seen, the developments of Kikoin's laboratory were quite diverse, effective, and in demand by industry. So that the reader does not get the impression that the laboratory's work was purely applied, I will also mention the fundamental research conducted there, which enriched world science: unique research on the gyromagnetic effect in superconductors, the discovery of the Kikoin–Noskov photoelectromagnetic effect in 1933, and a monograph, "The Physics of Metals" by Ya G Dorfman and I K Kikoin [24]. This is how I K Kikoin himself evaluates the work on the gyromagnetic effect: *This experiment was not only very difficult, but also beautiful in terms of technique, and I am still proud that we young experimental physicists of the 1930s managed to do this virtuoso experiment, which has now entered all textbooks and monographs as a classic. The results of the work were published in 1938* [19, p. 576]. The Kikoin–Noskov effect consists in the formation of an electric field in an illuminated semiconductor placed in a magnetic field.

In 1943, I K Kikoin involved only a few laboratory researchers in his work on atomic topics. Thus, Abram Konstantinovich Kikoin recalled: *My brother often left for Moscow, where the main work was being carried out, but the*

Vasilii Sergeevich Averkiev.

Vladimir Semenovich Obukhov.

Construction of Ural Physico-Technical Institute in Sverdlovsk, 1935.

I K Kikoin and M M Noskov, late 1930s (see the Kikoin–Noskov effect).

three researchers who remained in Sverdlovsk worked hard. Unfortunately, this work finally showed that the solution we were developing for the problem, given the technology available at the time, was not leading to the goal. In 1945, my brother and his family moved to Moscow [25, p. 17]. Abram Konstantinovich is referring to the development of a centrifuge method for enriching uranium. Fritz Lange — a German who emigrated from Nazi Germany in 1933 and accepted Soviet citizenship in 1937 — was ordered by the above-mentioned State Defense Decree No. 2352ss on the Organization of Work on Uranium of September 28, 1942 to develop a centrifuge for enriching uranium. The third participant in this work was Danil (Daniil) Lukich Simonenko.

Before starting the work, it was necessary to decide on a separation method. D L Simonenko recalled [26, p. 146] that *three methods were discussed*: *diffusion using cascading according to the Hertz scheme, centrifugal using sectioned centrifuges with axial circulation and, oddly enough, the photochemical method* [26, p. 146]. I K Kikoin wrote: *In the end, we decided to settle on the three methods. The centrifuge method was assigned to Kharkov professor F Lange, who had been working on this method while still in Germany. The electromagnetic method was taken over by L A Artsimovich, who had previously been working on electron optics. Ya B Zeldovich, who was involved in these matters, and I took up diffusion* [4, p. 6].

3. Electromagnetic separation of uranium isotopes

I will mention briefly the electromagnetic separation of uranium isotopes. Unlike the diffusion and centrifuge methods, in which the separation coefficient is fractions of a percent, for the electromagnetic method the separation coefficient theoretically reaches 100%, but the volume of the flow of the initial substance participating in the separation is small; that is, the amount of the separated substance obtained is correspondingly small [27, p. 11]. Of course, in practice, the electromagnetic method does not lead to complete separation of isotopes, but "high enrichment is achieved in a single operation" [28, p. 40]. Functionally and technically, this method is simpler than the diffusion or centrifuge methods: the only problem is the low efficiency of the method, although a combination of methods gives a synergistic effect. *If, for example, an electromagnetic installation can produce one gram of* 40% U-235 *per day from natural uranium, then, by increasing the concentration of* U-235 *in the source material by two times compared to the natural one* (1.4% *instead of* 0.7%)*, the same installation can produce* 2 *grams of* 80% U-235 *per day* [29, p. 223]. A plant for separating uranium isotopes by the electromagnetic method was built near the North Ural settlement of Nizhnyaya Tura (Sverdlovsk-45, now the city of Lesnoi) [30, p. 434]. After the start of industrial production of 90% uranium-235 by the diffusion method, the plant in Lesnoi was repurposed for other tasks.

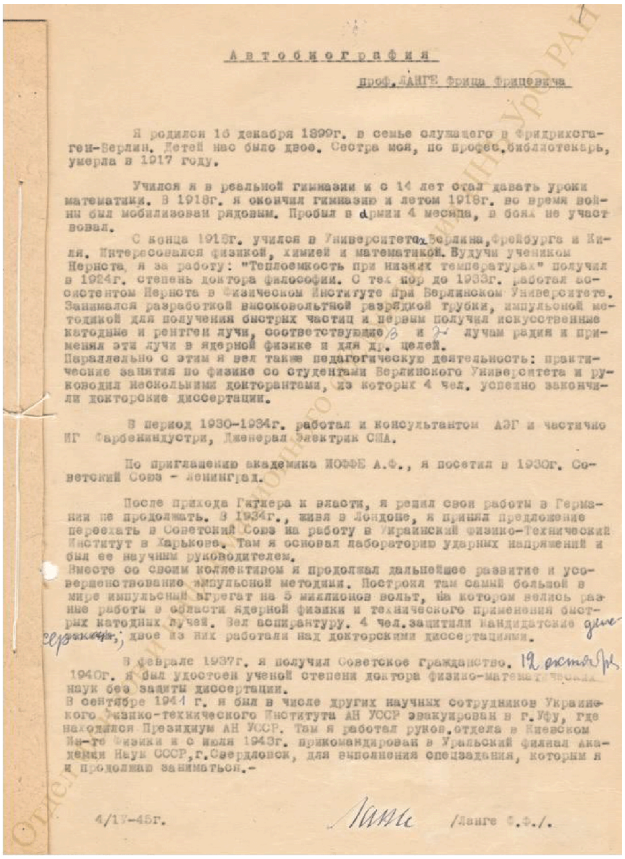
4. First studies using Lange centrifuge

The centrifuge method had a significant lead. In 1940, Lange's group filed an application for an invention "On the use of uranium as an explosive and toxic agent" (October 17, 1940, V A Maslov and V S Shpinel [31]). Soon after this, in 1940, F Lange, V A Maslov, and V S Shpinel filed an application for the invention of a "Method for preparing a uranium mixture enriched in uranium with a mass number of 235. Multichamber centrifuge," for which Author's Certificate No. 6359c was issued (the index c, meaning that the certificate was classified, appeared in 1945) [32]. No earlier than January 1 and no later than February 3, 1941, Lange's group filed an application for an invention "Thermocirculation centrifuge" [33]. If we have a close look at the mentioned documents, it becomes clear that these applications are actually just documented and patented ideas, and, as we can see, when organizing the USSR Atomic Project, the government went over the details of these applications.

I K Kikoin supervised the fabrication of the centrifugal machine in Ufa in 1943. Already at the assembly stage, he had to make improvements to the design [during initial tests, due to high loads (vibration), the bearings and torque shafts failed at high speeds]. Thus, they switched from ball to sliding bearings, improved the forced lubrication system, established constant temperature control of the bearings, carried out very careful balancing of the design, and manufactured centrifuges with several shaft diameters.

In a memorandum from I V Kurchatov to M G Pervukhin about the centrifuge tests on April 29, 1943 [34, p. 344], I K Kikoin wrote, *I consider it necessary to note that Professor Lange informed us in a very frivolous manner about the work he had done. Absolutely no experiments were performed on any model.... The machine parts are ill-conceived*; *in particular, I am very concerned about the vacuum sealing system, which was not tested even in a stationary state. In the presence of colossal centrifugal forces in a rotating machine,*

First building of Ural Physico-Technical Institute, 1935. Lange centrifuge was installed here.



Автобиография

проф. ЛАНГЕ Фрица Фрицевича

Я родился 16 декабря 1899г. в семье служащего в Фридрихсгаген-Берлин. Детей нас было двое. Сестра моя, по профес. библиотекарь, умерла в 1917 году.

Учился я в реальной гимназии и с 14 лет стал давать уроки математики. В 1918г. я окончил гимназию и летом 1918г. во время войны был мобилизован рядовым. Пробыл в армии 4 месяца, в бою не участвовал.

С конца 1918г. учился в Университете Берлина, Фрейбурга и Киля. Интересовался физикой, химией и математикой. Будучи учеником Нернста, я за работу: "Теплоемкость при низких температурах" получил в 1924г. степень доктора философии. С тех пор до 1933г. работал ассистентом Нернста в Физическом Институте при Берлинском Университете. Занимался разработкой высоковольтной разрядной трубки, импульсной методикой для получения быстрых частиц и первым получил искусственные катодные и рентген лучи, соответственно, и по лучам радия и применил эти лучи в ядерной физике и для др. целей.

Параллельно с этим я вел также педагогическую деятельность: практические занятия по физике со студентами Берлинского Университета и руководил несколькими докторантами, из которых 4 чел. успешно закончили докторские диссертации.

В период 1930-1934г. работал и консультантом АЭГ и частично ИГ Фарбениндустри, Дженерал Электрик США.

По приглашению академика ИОФФЕ А.Ф., я посетил в 1930г. Советский Союз - Ленинград.

После прихода Гитлера к власти, я решил свои работы в Германии не продолжать. В 1934г., живя в Лондоне, я принял предложение переехать в Советский Союз на работу в Украинский физико-технический Институт в Харьков. Там я основал лабораторию ударных напряжений и был ее научным руководителем.

Вместе со своим коллективом я продолжал дальнейшее развитие и усовершенствование импульсной методики. Построил там самый большой в мире импульсный агрегат на 5 миллионов вольт, на котором велись разные работы в области ядерной физики и технического применения быстрых катодных лучей. Вел аспирантуру. 4 чел. защитили кандидатские диссертации, двое из них работали над докторскими диссертациями.

В феврале 1937г. я получил Советское гражданство.

1940г. я был удостоен ученой степени доктора физико-математических наук без защиты диссертации.

В сентябре 1941 г. я был в числе других научных сотрудников Украинского физико-технического Института АН УССР эвакуирован в г. Уфу, где находился Президиум АН УССР. Там я работал руков. отдела в Киевском Ин-те физики и с июля 1943г. прикомандирован в Уральский филиал Академии Наук СССР, г. Свердловск, для выполнения спецзадания, которым я и продолжаю заниматься.-

4/IV-45г. /Ланге Ф.Ф./.

Autobiography of Professor Fritz Fritsevich Lange

I was born on December 14, 1899, into a family of an employee in Friedrichshagen, Berlin. There were two of us. My sister, a librarian by profession, died in 1917.

I studied at a real gymnasium and began to give mathematics lessons at the age of 14. In 1918, I graduated from the gymnasium and, in the summer of 1918, during the war, I was mobilized as a private. I spent 4 months in the army. I did not participate in battle.

From the end of 1918, I studied at the universities of Berlin, Freiburg, and Kiel. I was interested in physics, chemistry, and mathematics. As a student of Walther Nernst, I received a PhD in 1924 for my work "Heat capacity at low temperatures." From then until 1933, I worked as an assistant to Nernst at the Physics Institute of the University of Berlin. He was engaged in the development of a high-voltage discharge tube, a pulsed method for obtaining fast particles; I was the first to obtain artificial cathode rays and X-rays corresponding to the beta and gamma rays of radium and applied these rays in nuclear physics for other purposes.

In the period 1930–1934, I worked as a consultant for AEG and partially for IG Farbenindustrie AG and General Electric (USA).

At the invitation of A F Ioffe, I visited the Soviet Union (Leningrad) in 1930.

After Hitler came to power, I decided not to continue my work in Germany. In 1934, living in London, I accepted an offer to move to the Soviet Union to work at the Ukrainian Physics and Technology Institute in Kharkov. There, I founded a high-voltage laboratory and was its scientific director.

Together with my team, I continued the development and improvement of the pulsed method. There, I built the world's largest pulse unit for 5 million volts, which was used for various work in the field of nuclear physics and the technical application of fast cathode rays. I supervised postgraduate studies. Four people defended candidate dissertations; two of them worked on doctoral dissertations.

In February 1937, I received Soviet citizenship. On October 12, 1940, I was awarded the academic degree of Doctor of Physical and Mathematical Sciences without defending a dissertation.

In September 1941, I was among other researchers at the Ukrainian Physics and Technology Institute of the Academy of Sciences of the Ukrainian SSR evacuated to the city of Ufa, where the Presidium of the Academy of Sciences of the Ukrainian SSR was located. There, I worked as head of a department at the Kiev Institute of Physics and from July 1943 I was seconded to the Ural branch of the USSR Academy of Sciences, in the city of Sverdlovsk, to carry out a special assignment, which I continue to do.

F Lange

Autobiography of Lange. Department of Collections and Information Services of Central Scientific Library of Ural Branch of Russian Academy of Sciences (F. 1. Op. 2. D. 1114. L.1).

the situation will be significantly aggravated. We tried to fix some things on the spot, but the rest will have to be completed here.

F Lange brought to Sverdlovsk — to Kikoin's laboratory — a centrifuge manufactured at the Ufa Aviation Plant, designed by him specifically for experimental work on separating isotopes in the gas phase. The centrifuge, weighing about a ton, was mounted on a special foundation in the basement of the institute. In his memoirs, D L Simonenko wrote [26, p. 138], *In the spring of 1943, F Lange was assigned to the Laboratory of Electrical Phenomena of the Ural Branch of the USSR Academy of Sciences, headed by I K Kikoin. He*

F Lange (left) and A Brasch, 1930;
https://www.biblioatom.rU/persons/lange_fritz/#gallery.

F Lange in the laboratory;
https://www.biblioatom.ru/persons/lange_fritz/#gallery.

arrived at the laboratory in a somewhat unusual way. In the morning, a truck drove up to the main entrance to the building of the laboratory. Three soldiers and one man in civilian clothes were sitting in the open back of the truck on some boxes. One of the soldiers jumped off the truck, went inside the building, and quickly returned. After that, the soldiers began to unload the truck — heavy boxes and several suitcases were thrown out onto a flower bed. A woman got out of the cabin — she was dragging some bags and packages. The soldiers saluted the man in civilian clothes, jumped in the car, and drove away. The man and woman carried the suitcases under the pine trees, sat down, unwrapped the packages, and began to have breakfast. I was called to the directorate and told that there, at the entrance, is Professor Lange; he arrived from Ufa and brought with him some of the scientific equipment. I was instructed to arrange for Lange and his wife a temporary room in one of the small laboratories. The same day, all the boxes were moved to the laboratory and opened. The boxes contained the main parts of the centrifuge for separating isotopes.... As it turned out, this machine had never been assembled or tested in action. From I V Kurchatov's memorandum to the People's Commissar of the Chemical Industry M G Pervukhin of April 1, 1943 [35], *Professor Lange does not have a single employee at the moment, and Laboratory No. 2 is assigning him two of Kikoin's fellow researchers to speed up the work, that is, Comrades Simonenko and Polyakov....*

In his report to I V Kurchatov on the results of the trip to Sverdlovsk and the state of work on the centrifuge and diffusion unit, dated September 21, 1943 [36, pp. 391–393], I K Kikoin wrote, *It must be stated that too little has been done during the elapsed period. Professor Lange arrived in Sverdlovsk on July 17 of this year, and so by the time of my arrival he had been working together with Comrade Simonenko for about two months. Meanwhile, the centrifuge separation machine has not yet been put into operation. Moreover, the sealing system has not been checked. With a comparatively large number of alterations that were clearly necessary and which were not made, such a qualified mechanic as Comrade Polyakov was not busy with work. ...I was forced to admit that the state of the work was completely unsatisfactory. In connection with this, it was necessary to change the direction and nature of the work.* During the eight days Kikoin spent in Sverdlovsk, the situation changed for the better: *The seal at the gas inlet and outlet to the centrifuge, that is, in places where the system of concentric capillaries is sealed, was tested in a static state and at a low number of revolutions of the machine. The sealing system, after it was reconstructed with the help of comrade Polyakov, works quite satisfactorily.... Designers Comrades Averkiev and Bardin have now begun to draw up a draft design for a small installation with paired membranes.* As a result, the centrifuge was launched, and in the fall of 1943, F Lange and D L Simonenko performed more than 20 experiments on the centrifuge. They used mixtures of hydrogen with air and air with carbon dioxide as model mixtures. D L Simonenko recalled, *By the spring of 1944, we had already conducted a fairly large number of experiments, but we were unable to obtain stable gas circulation and repeatable enrichment data; we were getting completely random numbers from which it was impossible to draw any conclusions* [26, p. 150].

Danil (Daniil) Lukich Simonenko.

5. Assistance from Soviet intelligence

Soviet intelligence provided significant assistance in "organizing work on uranium." According to Vladimir Matveevich Chikov (all unreferenced quotes from this section are taken from V Chikov's book *Russian Illegals in the USA* [37]), the only scientist involved in studying the data obtained by intelligence was I V Kurchatov, who, realizing the full extent of his responsibility (it was assumed that some of the data could be erroneous or disinformation deliberately planted by American intelligence services), asked to allow I K Kikoin and his own brother B V Kurchatov to access the intelligence data. As Yu B Khariton recalls, Kurchatov was very critical of the intelligence materials, and "*He doubted whether the materials received reflected the actual course of scientific research work*," and assumed that they could turn out to be "*a fabrication whose purpose is to disinform our science*" [38, p. 135]. I V Kurchatov was surprised that "*Western scientists preferred the diffusion separation of isotopes to centrifuge separation*" [38, p. 135]. The intelligence data received from the intelligence officers [Dr. Emil Julius Klaus Fuchs (code-named 'Charles') and Arthur Fielding (code-named 'Perseus')] had to be rechecked in order to determine their "*objectivity and reliability of the sources*." Kikoin's group was engaged in the verification. In his review (July 27, 1944) about the materials received from intelligence and related to the gaseous diffusion method of separating isotopes, Kikoin wrote, "*We ourselves were engaged in solving this problem and came to similar conclusions*." In the Manhattan Project, Klaus Fuchs was involved in the development of the gaseous diffusion method of separating uranium isotopes, which was adopted as an industrial method in England and the USA. Of course, the intelligence data significantly accelerated the process. Thus, I K Kikoin writes, *The calculation made in this work is very ingenious and can be used in the detailed design of the machine. ...This last work is of the greatest interest, because it gives an idea of the production scheme of the*

separation plant. In a memorandum of March 7, 1943, devoted to the analysis of data provided by Soviet intelligence, I V Kurchatov wrote, *The most valuable part of the materials relates to the problem of isotope separation*. 1. *The only rational way to solve it is to separate the isotopes using diffusion through a membrane with small holes. The preference for the centrifuge method was unexpected for our physicists and chemists. We had a widespread point of view according to which the prospects of the centrifuge method were significantly higher than the prospects of the diffusion method, which was considered practically inapplicable for separating the isotopes of heavy elements. In accordance with this point of view, when initially setting up work on the uranium problem, research was envisaged only by centrifuge* (*Lange's method*) [39, p. 314]. The fact that the Soviet Atomic Project was not a blind copy of the American one is evidenced by the fact that the centrifuge method, as more energy-efficient, was not discarded and, despite the fact that it was technically more complex, was brought to fruition. Thus, on January 15, 1958, the experimental centrifuge plant of the Urals Electrochemical Combine began producing the first highly enriched uranium-235 of specified concentration [40]. Thus, diffusion cascades were subsequently replaced with centrifuge cascades in the USSR.

6. Beginning of work on Atomic Project in Sverdlovsk

On April 12, 1943, based on a decision by the State Defense Committee, the Academy of Sciences adopted a resolution on the creation of a new Laboratory No. 2 under the leadership of Kurchatov. While the laboratory did not have its own premises, the scientists involved in the Atomic Project worked at their 'old' workplaces, formally listed as seconded from Laboratory No. 2 to their former work.

From a memorandum of I V Kurchatov on the work plan of Laboratory No. 2 for the second half of 1943: *By the end of 1943, Laboratory No. 2 assumes*: 1. *To separate uranium isotopes and obtain several milligrams of uranium-235 using an ultracentrifuge*. ...3. *To conduct experiments and calculations necessary for the design of a diffusion machine for isotope separation* [41, p. 386]. The work plan itself states that Kikoin, Lange, and Simonenko were working on point 1. Point 3 of the program was implemented by Kikoin and Polyakov.

This point was specified: (a) *selection and study of the physicochemical properties of the working liquid, September 1, 1943*; (b) *selection and calculation of the main dimensions of the machine, October 1, 1943*; and (c) *development of a method for obtaining membranes for a model of a diffusion machine, December 1, 1943*. In his report to I V Kurchatov on the results of the trip to Sverdlovsk and the state of work on the centrifuge and diffusion installation of September 21, 1943 [36, p. 392], I K Kikoin stated that "*experiments on the diffusion method of separation were not carried out during my absence because Comrade Simonenko was very busy with the centrifuge*."

The level of secrecy can be judged by the memoirs of Pavel Akimovich Khalileev, a fellow researcher at the Institute of Metal Physics of the Ural Branch of the Russian Academy of Sciences [42, p. 19], who was involved in the work on separating uranium isotopes several years later in January 1947. *I knew very little about him* [Fritz Lange]. *I heard that he fled Germany from Hitler long before the war and worked in Kharkov. Then, during the war, he was evacuated along with the Kharkov Physicotechnical Institute somewhere in Central Asia, and, in 1943, Kikoin took him to Sverdlovsk and set up a laboratory for him in the basement, where outsiders were strictly prohibited from entering, since Fritz was conducting very secret work*. [*Many years later, I learned that Fritz was developing a centrifuge for separating isotopes in his basement* (*alas, unsuccessfully*)].

In September 1945, in his report "On the Separation of Uranium Isotopes" at a meeting of the Technical Council of the Special Committee under the State Defense Committee, Kikoin gave a "brief overview of isotope separation methods" implemented at Laboratory No. 2 of the USSR Academy of Sciences. The report discussed the centrifuge method [43, p. 370]: *In 1943, an experimental centrifuge using the Lange method* (*a centrifuge with a* '*countercurrent*') *was built at Plant No. 26 of the People's Commissariat of the Aviation Industry* (*in Ufa*), *and the same year it was installed in Kikoin's laboratory in the Ural branch of the USSR Academy of Sciences in Sverdlovsk. For almost two years, with the participation of Professor Lange, experiments were conducted on it to separate gas mixtures with the aim of studying the properties of such a centrifuge and in the hope of obtaining small quantities of uranium enriched in light isotope.... But, in view of the complexity and capriciousness of this method and, mainly, in view of the low productivity that can be expected from such a device* (*about* 0.01 g *per day per meter of length*), *we decided to abandon the industrial implementation of such a machine*. From the above documents, it follows that Kikoin was not very pleased with Lange. Khalileev recalls the time (1943–1944) when Lange and Obukhov were still working in Sverdlovsk [42, p. 19]: *Volodya Obukhov, on his own initiative, told me that Lange and Kikoin had had a skirmish, that they had had a heated argument and quarreled. And after this quarrel, Lange, agitated, walked back and forth in his room and talked loudly to himself. Obukhov heard this speech perfectly well through the loosely closed door that connected their rooms. The essence of Lange's outpourings was that he was beating himself up.—I shouldn't have argued so sharply with Kikoin. I should have made concessions. After all, I owe him so much*; *he got me out of some jams. And the work must be continued*; *if successful, it will be such help to the Soviets and the middle finger to Hitler!* But the main reason for the refusal '*from the industrial implementation*' of Lange's centrifuge was not Fritz Lange's mastery of the '*noble art of spoiling relations with his superiors*' (V P Nasonov even put this statement in the title of his article about Fritz Lange [44]), but the fact that it became clear that the centrifuge method had more difficulties than the diffusion method and that the required quick result could not be achieved.

However, work on the centrifuge method was not completely closed. In a report on the state of work on obtaining and using atomic energy of January 17, 1946 in the section "Organization of new laboratories" [45, p. 418], the First Chief Directorate informed I V Stalin: *The Special Committee decided to organize the following laboratories with special tasks in the field of the use of atomic energy in 1946*. 2. *Laboratory No. 4* (*under the direction of Professor Lange*) *for the development of a method for enriching the uranium-235 isotope using centrifugation*.

In their memorandum "The state of the problem of separating uranium isotopes," dated January 4, 1944 to M G Pervukhin (deputy chair of the Council of People's Commissars of the USSR, people's commissar of the Chemical Industry, curator of the creation of the Soviet atomic bomb on behalf of the Council of People's Commis-

sars of the USSR), I K Kikoin and A I Alikhanov wrote [46, p. 339], "*The problem of making membranes is one of the decisive ones for the construction of a large installation. ...It seems to us necessary to organize a group of people specifically working on this problem. We are currently busy finding the appropriate workers. Although it should be noted that we do not know of any specialists in this area at the moment.*"

In his report "On the state of work on the problem as of 27 November 1943" to M G Pervukhin [47, p. 405], I V Kurchatov stated: *Independently of the Central Aerohydrodynamic Institute* (*TsAGI*), *the laboratory in Sverdlovsk* (*Kikoin*) *is developing a simplified model of a diffusion machine. At the moment, design work is underway and individual units are being manufactured.*" Already at the end of 1943, Kikoin's group began research on the only gaseous compound of uranium at relatively low temperatures: *The first small portion of uranium hexafluoride in the amount of* 100 g *was synthesized at the request of I K Kikoin at the end of 1943 at the Radium Institute, headed by Professor V G Khlopin. Having synthesized this substance, I K Kikoin, still in Sverdlovsk, with the help of his colleagues D L Simonenko, V S Obukhov, and V N Tyushevskaya, conducted a detailed study of its main physical properties, which must be known to carry out the diffusion process. They are the dependence of vapor elasticity on temperature, heat capacity, viscosity, and the speed of sound* [4, p. 14].... *It was shown that the triple point of uranium hexafluoride, where three phases* (*gas, liquid, and solid*) *converge, is the temperature of* 64 °C *and pressure of about* 1.5 atm. *At a pressure below* 1 atm *and a temperature below* 56 °C, *uranium hexafluoride vapors are close in their properties to an ideal gas and can be condensed into a solid crystalline phase*" [4, p. 14]. I will add information about the high chemical aggressiveness of uranium hexafluoride, which has added many difficulties to the development of gas-diffusion technology for separating uranium isotopes.

It reacts with almost all chemical elements and, having given up some of its fluorine, turns into a stable solid compound — uranium tetrafluoride. Uranium hexafluoride reacts with water, forming aggressive hydrofluoric acid, and does not tolerate organic compounds or oils. Other products of uranium hexafluoride reactions form solid corrosive deposits on the surfaces of equipment [4, p. 15].

"*We* — recalls D L Simonenko — *did not imagine how many technical difficulties would be associated with the properties of the vapors of this compound: the ability to react with metal surfaces and water vapor, to decompose, to settle on walls in the form of nonvolatile compounds, etc. It was known that to work with it, it was necessary to have vacuum-tight equipment with well-dehydrated surfaces*" [4, p. 40].

7. Porous filters

One of the main elements of gaseous diffusion technology is porous filters, in which the isotope separation process takes place. Lighter atoms pass through the pores of the filter more easily, and the gas mixture at the outlet is enriched with the light fraction. Thus, the enrichment factor, the separation performance of diffusion cascades, the duration of their service life, and the cost-effectiveness of the method are determined by the quality of the porous filters. I K Kikoin wrote, "The filters were made by experienced mechanic Ivan Nikolaevich Polyakov. They were made of copper foil several hundredths of a mm thick, pricked with a thin needle" [4, p. 8]. In 1944, "skilled mechanic I N Polyakov designed an automatic machine that punched holes in thin copper foil (0.2 mm)" [4, p. 17]. The average pore diameter should be as small as possible to approach the theoretical limit of uranium isotope separation (maximum enrichment factor on the filter is 4.3×10^{-3}), and so the mechanical principle of filter manufacturing had to be abandoned soon.

8. Transfer of work from Sverdlovsk to Moscow

In 1945, the scientific group of I K Kikoin's fellow researchers was transferred from Sverdlovsk to Laboratory No. 2 of the USSR Academy of Sciences in Moscow (later, the I V Kurchatov Institute of Atomic Energy). In the report on the state of work on obtaining and using atomic energy of January 17, 1946 [45, p. 415], the First Chief Directorate informed I V Stalin: *Laboratory No. 2 is working on the following issues*: ...2. *On the development of an industrial method for obtaining uranium-235 by the diffusion method, on the design and construction of diffusors using this method. The work is headed by Corresponding Member of the USSR Academy of Sciences Professor I K Kikoin and Corresponding Member Professor I N Voznesensky. Academician S L Sobolev and senior research fellows D L Simonenko and V S Obukhov take part in the work...* .

In 1948, Vladimir Semenovich Obukhov became head of the porous partitions sector in Laboratory No. 2. *Sector No. 2* (*I K Kikoin, V S Obukhov, V Kh Volkov, K V Glinskii, V N Tyushevskaya, and others*) *together with the Moscow Hard Alloy Plant* (*MKTS*) *developed a technology for manufacturing flat filters in the form of porous plates from finely dispersed powder with the formation of a blank in a press mold installed on a vibration stand, with subsequent sintering. The first such filters were fabricated and tested at the end of 1945. At the beginning of 1946, a closed competition was announced for the development of flat filters according to the technical specifications developed by Sector No. 2. Six development areas were tested in parallel. The most successful was the above-mentioned version, developed under the supervision of I K Kikoin. It was accepted for production at the MKTS. All the machines of the first gaseous diffusion plant D-1 were equipped with these filters. ...For reasons of secrecy, the flat filters were called 'cards'* (*they were similar in size to a playing card*). *The characteristics of these filters have been determined since 1946 in Department 'D'* (*former Sector No. 2*) *in V S Obukhov's sector. On an experimental setup manufactured in mechanical workshops according to drawings by the Design Bureau of Department 'D,' K S Panyukhina and V S Obukhov were the first to study the primary separation effect on small samples of a flat filter* [4, p. 17]. Later, more advanced tubular filters were developed. *The first detailed studies of tubular filters in I K Kikoin's department were conducted in mid-1948 by a group that included S S Shalyt, V S Obukhov, M N Sagalovich, K V Glinsky, B V Zhigalovsky, and B N Denisov. As a result, the significant advantages of tubular filters were confirmed, ways to improve them were outlined, and recommendations were issued for their use in second-generation diffusion machines. In addition to improving the separation properties, tubular filters made it possible to significantly simplify the design of parts, that is, to make them more compact and convenient for assembly* [4, p. 19]. Below is an excerpt from Appendix No. 2 of the Resolution of the USSR Council of Ministers (No. 1127-402ss/op "On the plan for special scientific research work for 1948") [51]. According to the work plan, the development of tubular filters with small pores

and experiments with them on a 20-stage frame were planned for the 2nd quarter of 1948 [51, p. 415].

Until 1952–1953, V S Obukhov continued research aimed at improving porous filters. This is how P E Suetin recalls it in his article, "At the origins of the atomic problem" [52]: *A week later, we entered the laboratory territory and found ourselves in the Department of Thermal Control Devices (OPTK), which at that time was headed by Professor I K Kikoin. We were assigned to different facilities of the OPTK. I ended up in the department headed by Professor V S Obukhov, who was brought to Moscow, to the laboratory, by I K Kikoin from the Urals from the Ural Branch of the USSR Academy of Sciences in 1944. Vladimir Semenovich suggested that I study the resistance of a tubular diffusion filter as a function of the amount of gas outflow through its porous wall. We discussed the layout of the experimental setup. In my supervisor's office they put a drawing table for me, on which I spent a month drawing the layout of the setup. During this time, I met many participants in the diffusion project, who often came into Vladimir Semenovich's office. They were project theoreticians S L Sobolev, M E Millionshchikov, and Ya A Smorodinsky, and experimenters D L Simonenko and I A Savel'ev... . After the drawings of the setup were made, they were handed over to the workshop. I should say that the laboratory had a large mechanical workshop equipped with all the necessary machines and serviced by highly qualified craftsmen. ...The manufacture of the setup was delayed, since many fundamental problems of diffusion separation had been solved or were already being solved at the plant in Verkh-Neyvinsky (Sverdlovsk-44) in the Urals. ...Getting acquainted with other work of the laboratory, to put it mildly, was not welcome. For example, I did not know the topics of the diploma theses of my friends and graduate students. We did not discuss our work with people who were not directly related to the given topic, and also did not visit the neighboring rooms. The laboratory also had a mini-factory consisting of several dozen OK-6 machines, making up a model of a cascade, access to which was strictly limited and watched over by a separate guard. I got to this plant in 1955, when centrifuges were already there. Finally, in January 1951, the setup was complete, and we began experiments. Experimental studies, as often happens, were conducted in a completely different direction. The fact is that the gas passing through the porous wall is depleted of a light isotope (uranium) near its surface, which reduces the separation efficiency. It is necessary to organize intensive mixing of the gas inside the cylindrical tube. Natural turbulence is insufficient for this. It was proposed to improve gas mixing by placing a wire spiral inside the tube along its entire length, with the wire*

Постановление СМ СССР № 1127-402сс/оп
«О плане специальных научно-исследовательских работ на 1948 год»

г. Москва, Кремль — 6 апреля 1948 г.
Сов. секретно
(Особая папка)

	Наименование работ	Сроки исполнения	Основные исполнители
	Радиационная лаборатория АМН СССР (Научный руководитель – проф. Франк Г.М.)		
12.	Разработка методов использования *осколков* радиоактивных элементов, в т. ч.:		
	а) *военно-химическое* использование	II – IV кв. 1948 г.	***НИИ-42*** Гаврилов Г.И. Зимаков
	б) медико-биологическое использование.	– « –	***Радиационная лаборатория*** Франк Г.М.
	Раздел III. Лаборатория № 2 АН СССР (Научные руководители – чл.-кор. АН СССР Кикоин И.К. и акад. Соболев С.Л.)		
13.	Дальнейшие работы по методу, принятому в проекте № 1865 с целью создания более производительных машин, в т. ч.:		
	а) исследование механизма обогащения (исследование молекулярного течения, влияния геометрии, установление констант молекулярного течения);	август	***Лаборатория № 2*** Кикоин И.К. Соболев С.Л. ***Институт «Г»*** Герц
	б) разработка и изготовление опытных образцов компрессоров производительностью до 2,5 кг/с и их испытание;	октябрь	***Лаборатория № 2*** Кикоин И.К. ***Завод № 92*** Елян А.С. Савин А.И. ***Кировский з-д*** Кизима А.Л. Синев Н.И.
	в) разработка трубчатых фильтров с малыми порами и опыты с ними на 20-ступенчатом каскаде;	II кв.	***Лаборатория № 2*** Кикоин И.К. Обухов В.С. Шалыт С.С. ***Институт «А»*** Арденне ***Институт «Г»*** Герц ***Комб[инат] твёрд[ых] сплавов*** Ковальский А.Е.
	г) разработка предварительного проектного задания на проектирование завода производительностью до 2 000 усл. ед. в сутки конечного продукта А-95;	декабрь	***Лаборатория № 2*** Кикоин И.К. Соболев С.Л. ***ГСПИ-11*** Гутов А.И.
	д) исследование и выяснение наиболее целесообразных сочетаний различных методов разделения А-9.	III кв.	***Лаборатория № 2*** Кикоин И.К. Соболев С.Л. ***Ин-т физ. проблем*** Александров А.П.

Resolution of the USSR Council of Ministers No. 1127-402ss/op
"On the plan for special scientific research work for 1948"

Moscow, Kremlin — April 6, 1948
Top secret (Special folder)

	Name of work	Completion dates	Main performers
	Radiation laboratory of the USSR Academy of Medical Sciences (Scientific supervisor: Prof. G M Frank)		
12.	Development of methods for using fragments of radioactive elements, including:		
	(a) military-chemical use	II–IV quarter, 1948	Research Institute-42 Gavrilov G I Zimakov
	(b) medical-biological use.	-"-	Radiation laboratory Frank G M
	Section III Laboratory No. 2 of the USSR Academy of Sciences (Scientific supervisors: Corresponding Member of the USSR Academy of Sciences I K Kikoin, and Academician S L Sobolev)		
13.	Further work on the method adopted in project No. 1865 with the aim of creating more productive machines, including:		
	(a) study of the enrichment mechanism (study of molecular flow, influence of geometry, establishment of molecular flow constants);	August	Laboratory No. 2 Kikoin I K, Sobolev S L Institute 'G' Hertz
	(b) development and manufacture of pilot compressor models with a capacity of up to 2.5 kg per day and their testing;	October	Laboratory No. 2 Kikoin I K Plant No. 92 Elyan A S, Savin A I, Kirov Plant Kizima A L, Sinev N I
	(c) development of tubular filters with small pores and experiments with them on a 20-stage cascade:	II quarter	Laboratory No. 2 Kikoin I K, Obukhov V S, Shalyt S S Institute 'A' Ardenne Institute 'G' Hertz Hard alloys plant Kovalsky A E
	(d) development of a preliminary design assignment for the design of a plant with a capacity of up to 2000 conventional units per day of the final product A-95;	December	Laboratory No. 2 Kikoin I K, Sobolev S L GSPI-11 Gutov A I
	(e) study and clarification of the most appropriate combinations of various methods of separating A-9.	III quarter	Laboratory No. 2 Kikoin I K, Sobolev S L Institute for Physical Problems Aleksandrov A P

Excerpt from Appendix No. 2 of the Resolution of the USSR Council of Ministers (No. 1127-402ss/op "On the plan of special scientific research work for 1948") [51].

diameter being equal to the internal diameter of the separation tube. It was necessary to experimentally find the optimal dimensions of this spiral, that is, the diameter of the wire from which the spiral is made, and the pitch of the spiral. ...The experiments were conducted on a model gas — sulfur hexafluoride, which facilitated the analysis, since one of the sulfur isotopes was beta-active. We worked a lot, without regard for time or holidays. And we had nothing to be distracted by (*our families were in Sverdlovsk*); *despite the fact that we worked with gaseous sulfur, no special safety measures were taken. All safety was guaranteed by a mug of milk and a free lunch. ...On May 16, 1951, the defense of diploma theses took place in I K Kikoin's office. ...The State Examination Commission was chaired by I K Kikoin*; *also in attendance were L A Artsimovich, N A Dollezhal, S L Sobolev, M D Millionshchikov, V S Obukhov, Ya M Smorodinskii, and others.*

9. Reviewer's question

The reviewer asked an interesting and difficult question, which makes us look at the uranium enrichment epic from a different angle. *Since we created and tested a plutonium bomb 2 years earlier than a uranium bomb, what are the reasons* (*physical, economic, political, etc.*) *that forced the country to deal with the most difficult problem of separating uranium isotopes*? Uranium-235 and plutonium-239 have different physical characteristics, and by testing nuclear charges based on only plutonium-239, scientists would have had less experimental data on the processes occurring during a nuclear explosion.

Therefore, I believe that testing uranium bombs provided more information and allowed a better theoretical description and, accordingly, understanding of nuclear fission processes. In addition, combining plutonium and uranium charges made it possible to expand the characteristics of the nuclear charges being developed. It is clear that if thermonuclear bombs had not been created, then, in order to increase the range, for example, by the power of the explosion of the nuclear bombs used, uranium, plutonium, and combined nuclear charges would have been created. But in 1951, we began to develop thermonuclear devices. RDS-6s is the first Soviet hydrogen bomb, the so-called "Sakharov layer cake." (Work on creating the bomb began in 1950; it was tested at the Semipalatinsk test site on August 12, 1953.) One of the layers of RDS-6s consisted of uranium-235. The fact that a hydrogen bomb was being developed in the West, the design of which included "40% *uranium-235 in the amount of* 71 kg" [7, p. 247] was known in the USSR since 1948 from intelligence materials transferred by Klaus Fuchs. Thus, the main need to create highly enriched uranium-235 is to use uranium-235 as a component of a thermonuclear bomb.

Since the neutron background of plutonium is significantly greater than that of uranium-235, its transfer to a supercritical state without an incomplete explosion requires very fast cumulative spherically symmetric compression, unlike uranium-235, the transfer of which to a supercritical state can be carried out by the gun method.

Another factor determining the need to obtain enriched uranium is its use in research reactors. If in an RBMK-type industrial uranium-graphite reactor (high-power channel reactor) the enrichment of uranium-235 does not exceed 3.2%, then, in research reactors, the enrichment of uranium-235 can reach 90%. Thus, V V Goncharov recalls, *In 1957–1958, in order to expand the front of research work on atomic energy conducted under the author's supervision, a graphite research reactor* (*RFT*) *was reconstructed.... For the reconstructed reactor, fuel elements of a new design were developed with a highly developed cooling surface and uranium enriched with isotope-235 to* 90% (*instead of* 10%) [53, p. 235].

How scientists and the government viewed this issue in 1951 can be understood from the report, "On the progress of fulfilling the tasks for 1951 and on the work program for the development of the atomic industry in 1951–1955" of November 16, 1951. The report was handed over to I V Stalin and signed by L P Beria, B L Vannikov, A P Zavenyagin, I V Kurchatov, Yu B Khariton, and K I Shchelkin [54, p. 342]. Some data were removed from the document for reasons of secrecy, but what remains is sufficient to clarify the situation. *In connection with the significantly greater power of the RDS-2* [*with a charge of* (...) *plutonium and a total weight of* 3.1 tons] *and RDS-3* [*with a charge of* (...) *uranium-235 and* (...) *plutonium*] *tested in 1951, production of RDS-1 products has been discontinued and production of RDS-2 and RDS-3 has begun. In 1952, 40 RDS products will be manufactured* (*including 24 RDS-2 and 16 RDS-3*). *The 29 RDS-1 products manufactured before November 1, 1951 will be converted into RDS-2 products* (*19 in 1952 and 10 in the first half of 1953*) [54, p. 342].... *The successful results of testing the RDS-3 product with a composite charge of uranium-235 and plutonium showed the need to expand the production of uranium-235. In connection with this, a decision was made to build a second diffusion plant with a capacity of 600 kg of uranium-235 per year. The new diffusion plant will duplicate Plant No. 813 and will be built as part of Plant No. 816* [54, p. 348].... *The production of uranium-235* (75% *concentration*) *will be* 77 kg *in 1951,* 152 kg *in 1952,* 600 kg *in 1955, and* 1242 kg *in total for the five-year period* (*1951–1955*). *At present, uranium-235 is produced at Combine No. 813, which includes one diffusion plant and a second one under construction. The total capacity of both plants at Combine No. 813 will be 600 kg of uranium-235 per year. Nine thousand eight hundred eighty diffusion machines are operating at the first plant. The second plant will be put into operation in the second half of 1952. A total of 15,800 diffusion machines will be operating at Combine No. 813* [54, p. 347]. The same report [54, p. 344] describes the advantages of uranium-235 compared to plutonium: *According to preliminary calculations by Design Bureau No. 11, the atomic charge of such an RDS product should consist of* (...) *uranium-235 with a small addition of* (...) *plutonium. The possibility of using large quantities of uranium-235 in atomic charges is explained by the fact that, unlike plutonium, uranium-235 has a low neutron background.* The report also highlights possible difficulties: *Development of a charge weighing* (...) *uranium-235 will require a great deal of work on the additional study of the nuclear properties of uranium-235 and complex development of the design of the atomic charge of the product.*"

10. Ural Electrochemical Combine

The uranium isotope separation plant (Ural Electrochemical Combine or Combine No. 813) built in the city of Sverdlovsk-44 near the settlement of Verkh-Neyvinsky was mentioned above. It is impossible to cover this part of history in detail within the framework of one article. I will only mention a few facts. Yu M Kagan wrote, "Back in 1945, I K Kikoin chose a site for the construction of a diffusion plant in the Urals, 60 km from Sverdlovsk" [55, p. 13]. I K Kikoin was one of the

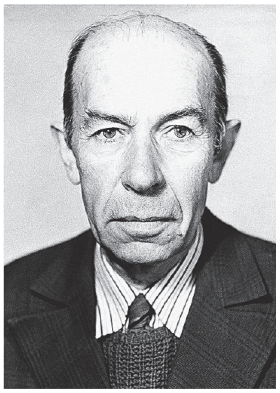
founders of the combine, supervised commissioning work in 1948–1949, and from 1949 to 1953 was deputy director of the plant for scientific work. To intensify work on launching the diffusion plant, on May 22, 1948, I K Kikoin was appointed "scientific director and deputy director of the State Machine-Building Plant" (referring to the Ural Electrochemical Combine in Sverdlovsk-44) [56, p. 472].

11. Pavel Akimovich Khalileev

Pavel Akimovich Khalileev defended his candidate's dissertation under the supervision of I K Kikoin in 1936.

Beginning in 1937, he was engaged in magnetic flaw detection, and, in 1946, he received the Stalin Prize of the

P A Khalileev testing his magnetometer ("marine magnetic direction finder"), 1945–1946.



Pavel Akimovich Khalileev.

P A Khalileev after receiving the Stalin Prize (USSR State Prize), 1946.

Халилееву
Павлу Акимовичу
в 1946 году присуждена Государственная премия СССР
третьей степени и присвоено звание
ЛАУРЕАТА ГОСУДАРСТВЕННОЙ ПРЕМИИ СССР
за разработку новой аппаратуры для обнаружения затонувших кораблей

Председатель Комитета по Ленинским премиям в области науки и техники при Совете Министров СССР (М. Келдыш)

№ 6605

„20" октября 1962 г.

Ученый секретарь Комитета по Ленинским премиям в области науки и техники при Совете Министров СССР (Н. Аржаников)

Pavel Akimovich Khalileev
in 1946 was awarded the USSR State Prize
of the third degree and the title
of LAUREATE OF THE USSR STATE PRIZE
for the development of new equipment
for detecting sunken ships

Chairman of the Committee on Lenin Prizes in Science and Technology under the Council of Ministers of the USSR (M Keldysh)

October 20, 1962

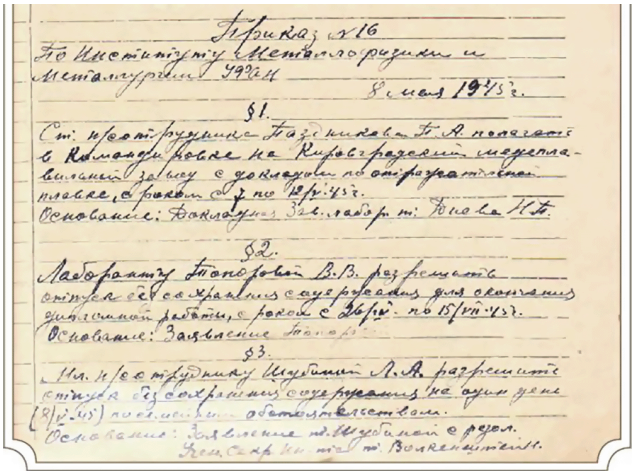
Scientific Secretary of the Committee on Lenin Prizes in Science and Technology under the Council of Ministers of the USSR (N Arzhanikov)

P A Khalileev's certificate of the Laureate of the State Prize.

third degree for the development of new equipment for detecting sunken ships. With the help of the "marine magnetic direction finder," at the end of the Great Patriotic War and in the first post-war years, more than 130 German and our sunken or submerged ships were found and raised. This was the second State Prize received by researchers from the institute. In May 1947, P A Khalileev was transferred to Plant No. 813 in Sverdlovsk-44, as the head of the physical sector of the Central Plant Laboratory (CPL) of the Ural Electrochemical Combine, and later headed the Gas Centrifuge Laboratory founded on May 3, 1954. In 1961, for the "development and mastering of the centrifuge method of separating uranium isotopes," P A Khalileev (together with M D Millionshchikov, V I Sergeev, H A Murinson, E M Kamenev, K V Glinsky, B S Chistov, and M L Raikhman) was awarded the Lenin Prize [57, p. 143].

12. Trip to Berlin in May 1945

I would like to mention one more episode of our history connected with the Atomic Project, namely, the trip of the 'trophy team' of nuclear scientists from Moscow to Berlin in early May 1945. This episode, based on the memoirs of I K Kikoin, Yu B Khariton, and D L Simonenko, is



Order No. 16

for the Institute of Metal Physics and Metallurgy of the Ural Branch of the USSR Academy of Sciences

May 8, 1945

No. 1

Senior research fellow P A Pozdnyakov is to be sent from May 7 to May 12, 1945 to the Kirovograd Copper Smelter to report on reflective smelting.

Reason: report by head of the laboratory, comrade Diev N P.

No. 2

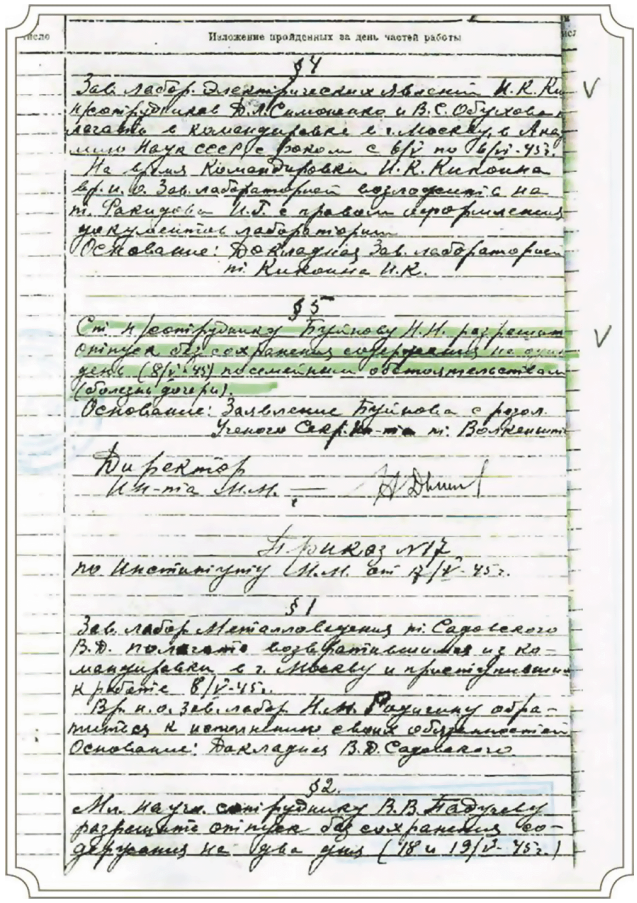
Laboratory assistant V V Toporova is to be allowed unpaid leave to complete her thesis from April 26 to July 15, 1945.

Reason: statement by V V Toporova

No. 3

Junior research fellow L A Shubina is to be allowed unpaid leave for one day (May 8, 1945) due to family circumstances.

Order No. 16 of May 8, 1945 (page 1) signed by N V Demenev.



No. 4

Head of the Laboratory of Electrical Phenomena Kikoin I K and research associates D L Simonenko and V S Obukhova are to be sent to the USSR Academy of Sciences in Moscow from May 6 to June 6, 1945.

During I K Kikoin's business trip, the duties of the acting head of the laboratory shall be assigned to Comrade Fakidov I G with the right to draw up laboratory documents.

Basis: report of Head of Laboratory Kikoin I K.

No. 5

Senior research associate Buinov N N is to be allowed unpaid leave for one day (May 8, 1945) due to family circumstances (daughter's illness).

Basis: statement of Comrade Buinov with the resolution of the scientific secretary of the institute comrade Volkenshtein.

Director
of the Institute of Metal Physics and Metallurgy N V Demenev

Order No. 17

for the Institute of Metal Physics and Metallurgy of the Ural Branch of the USSR Academy of Sciences May 17, 1945

No. 1

To consider the head of the metal science laboratory, Comrade V D Sadovsky, to have returned from a business trip to Moscow and to have begun work on May 8, 1945.

Acting Head of the Laboratory N M Rodigin shall begin performing his duties.

Basis: report by Comrade V D Sadovsky.

No. 2

Junior research fellow V V Paduchev is to be allowed unpaid leave for two days (May 18 and 19, 1945).

Order No. 16 of May 8, 1945 (page 2), signed by N V Demenev. Point 4: order to send I K Kikoin, D L Simonenko, and V S Obukhov to Moscow.

described quite well, and so it will be presented here only in brief.

The group of 'trophy men' was headed by the Deputy People's Commissar of Internal Affairs, Colonel General Avraamii Pavlovich Zavenyagin, who was appointed on December 8, 1944 (GKO Resolution No. 7102ss/ov on accelerating geological exploration work for uranium) and was responsible for the search for uranium in the USSR and in the occupied territories.

All the scientists temporarily became Soviet officers. Thus, I K Kikoin and Yu B Khariton received uniforms with colonel's shoulder straps, and D L Simonenko had the rank of major.

This is how Simonenko recalls it: *The next day* (*May 6*), *I witnessed I K Kikoin putting on a colonel's uniform. It was strange and unusual to see him with shoulder straps. 'I'm going to Germany,' he said, but where exactly and why remained unclear. The next day* (*May 7*), *I V Kurchatov told me on the phone, 'Tomorrow you must receive a uniform and go to Berlin with a group of comrades.' 'Why?' I asked, somewhat impertinently. This, apparently, angered I V Kurchatov. He said quite authoritatively, 'What do you mean, why? You want to work in an equipped laboratory, don't you? So, go and get everything you need. Got it? You need to think! Report to Colonel P V Khudyakov at once?*' [58, p. 660].

During their 45-day stay in Germany, the 'trophy hunters' accomplished a lot. Thus, D L Simonenko participated in the events to deliver uranium oxide reserves discovered in Germany and a huge magnet for the cyclotron seized from M Ardenne to the USSR. The obtained equipment and materials, of course, were extremely useful for the atomic project, being developed from scratch, but the most valuable items were the 130 tons of uranium oxide U_3O_8 'obtained' by I K Kikoin and Yu B Khariton through an almost detective search [59, p. 120].

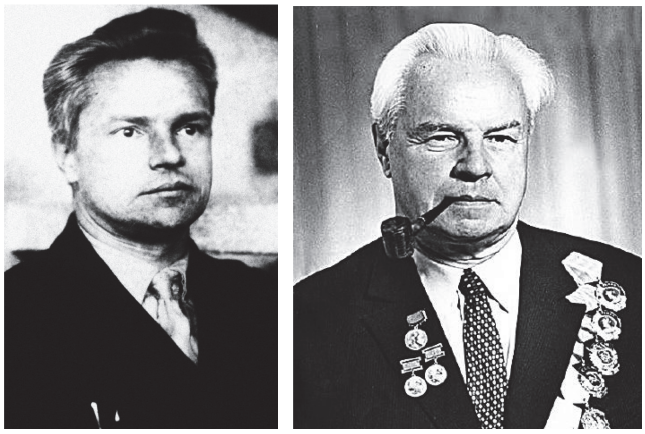
As I K Kikoin and Yu B Khariton understood from the obtained reports on the German Atomic Project, the Germans lagged significantly behind the USSR.

Therefore, *Kikoin and I decided — recalled Yu B Khariton — that we needed to do something else. Since the Germans had occupied practically all of Europe, they were also in Belgium. As everyone knows, there are large uranium deposits in the Congo, a Belgian colony in Africa, and therefore it is very likely that the Germans had captured some uranium in Belgium, and we needed to find out where this uranium was. So, we started working.... We told A P Zavenyagin about the need to search for uranium, and he warmly supported it. He put a car with a driver at our disposal so that we could travel freely around Germany*'' [60].

Yulii Borisovich Khariton recalled, ''Kurchatov once told me that the uranium found in Germany had shortened the launch date of the first industrial reactor for plutonium production by about a year'' [59, p. 121].

13. Second wave of Sverdlovsk scientists to the Atomic Project

In 1949, other fellow researchers at the Institute of Metal Physics of the Ural Branch of the USSR Academy of Sciences were attracted to the Atomic Project in Sverdlovsk-44 at the Ural Electrochemical Combine, including M V Yakutovich, S V Karpachev, and S K Sidorov. Also, ''candidates of the chemical sciences Yu V Karyakin and B N Lundin came from Sverdlovsk'' [61, p. 103].



Mikhail Vasil'evich Yakutovich.

Mikhail Vasil'evich Yakutovich, who worked as deputy director and head of the laboratory of mechanical properties before his transfer, was appointed deputy scientific director of the Ural Electrochemical Combine (from 1953 to 1962, scientific director). M V Yakutovich *supervised the work on the development of new equipment for separation production and the improvement of technological processes for isotope separation by gaseous diffusion and centrifuge methods* [61, p. 103].

Sergei Vasil'evich Karpachev was director of the Institute of Metal Physics from July 1, 1948 to July 1949, and head of the Electrochemistry Laboratory [part of the Ural Physico-Technical Institute (Institute of Metal Physics UB RAS) in 1936–1939]. In November 1949, I K Kikoin — the scientific director of the Combine — was concurrently appointed head of the Central Plant Laboratory (CPL), and his deputy was S V Karpachev (in 1953–1956, head of the CPL) [62, p. 237].

Sergei Vasil'evich Karpachev.

14. First diffusion plant D-1

The reason why the 'second wave' of scientists was sent to Combine No. 813 *was the failure to meet the deadlines for commissioning the first diffusion plant D-1 for separating uranium isotopes. When starting up the cascades of diffusion machines, the level of corrosion* (*decomposition*) *of uranium hexafluoride was found to be unacceptably high. It turned out*

that, when passing a flow of uranium hexafluoride enriched in uranium-235, a significant portion of it gradually converted into uranium tetrafluoride and was deposited in the form of powder on the internal surfaces of equipment and pipelines. As a result, a significantly smaller portion of the gas reached the final stage of the cascade [63].... *At the Central Plant Laboratory, S V Karpachev is involved in research on the interaction of new materials and products with the working gas* (*uranium hexafluoride*), *the development of improved tubular cards, and the creation of new types of diffusion filters*'' [63].

In 1950, four sectors were formed in the Central Plant Laboratory, including physical (headed by P A Khalileev) ''for studying the measurement of the isotopic composition of uranium and research into the various capabilities and structure of porous media''; chemical (headed by Yu V Karyakin) ''for analyzing the quality of products (uranium and impurity content), research into anti-corrosion protection of equipment, development of lubricants resistant to aggressive environments, and chemical-technological research''; and technological (headed by S K Sidorov) ''for testing the main equipment, condensation/evaporation installations, and diffusion filters'' [61, p. 104]; laboratories were also organized: the Laboratory of Mass Spectrometry and the Laboratory of Radioactive Methods. ''Their general supervision was carried out by P A Khalileev, the head of the physical sector'' [61, p. 108].

In general, how many machines were included in the cascades of the first diffusion plant and how reliably did the compressors work? *For a long time, it was necessary to replace around the clock the stopped compressors with new or repaired ones. Only in 1949 was the true cause of the failure of the bearings established — their excessive precision and incorrect fit in the electric motor housing. After replacing the bearings on all* (*more than 5500*) *compressors and adjusting the fit, the machines stopped failing*. There were enough problems even without compressors. Thus, in 1948, *...the plant worked, but did not produce the designed products. Uranium enriched to only* 40% *was produced. I V Kurchatov instructed L A Artsimovich to bring this uranium to bomb condition in the experimental electromagnetic installation in Laboratory No. 2. During a month of its round-the-clock operation,* 400 g *of uranium containing from* 92% *to* 98% *uranium-235 were produced from* 40% *enriched uranium. By mid-1948, theoreticians' calculations demonstrated that it was impossible to produce uranium enriched to* 90% *with the plant's design configuration*

Cascade of the largest T-56M diffusion machines;
https://www.biblioatom.ru/persons/karpachev_sergey_vasilevich/#gallery.

Diffusion cascade;
https://www.biblioatom.ru/persons/simonenko_daniil_lukich/#gallery.

of diffusion stages. It was necessary to change the D-1 design and introduce an additional 1000 gas diffusion stages into the process flow chart. New machines were developed for the additional stages, featuring reduced corrosion losses of highly enriched gas and an increased degree of gas compression in the compressor. *To ensure the design capacity and start-up of the plant, it was permitted to replace 896 LB-7 machines with 1696 small LB-6 machines with reduced losses, and assemble and commission them by May 15, 1949*. In November 1949, ''*it was possible to obtain the first* 75% *enriched product in a small* (*far from the calculated*) *amount*; *it was decided to take this still substandard product from the D-1 plant and enrich it to* 90% *at the electromagnetic plant created under the leadership of L A Artsimovich in the Northern Urals. ...In 1950, after replacing all engines on the LB-7 and LB-8 machines and performing passivation treatment on all internal surfaces of the machines, including porous filters, and fully commissioning the water cooling station* (*to 8–10* °C) *and the dry air shop, the D-1 plant finally began to operate normally. The enrichment of the final product with uranium-235 was brought from* 75% *to* 90% *of the calculated value. The electromagnetic plant stopped additional enrichment of uranium and started separating stable isotopes* [4, pp. 40–44].

The difficulties were overcome, and the diffusion plant was put into operation. The merits of the developers were highly appreciated. Thus, on December 6, 1951, the group headed by I K Kikoin, which included the above-mentioned V S Obukhov, D L Simonenko, M V Yakutovich, S V Karpachev, and I N Polyakov, was awarded the Stalin Prize of the first degree for the development and industrial implementation of the production of uranium-235 by the gaseous diffusion method with the wording: ''to the leaders of work on the separation of uranium isotopes by the diffusion method'' (see document excerpt below [64]). *In 1951, a year after the first kilograms of uranium enriched to* 90% *with uranium-235 were produced at the D-1 plant, the first uranium bomb made from this explosive material was tested. This was two years after the first plutonium bomb was tested* (*1949*). *Subsequently, domestic plants also began to produce uranium of low enrichment* (*up to* 5%) *for nuclear power plants* [4, p. 53].

Soon after the first gaseous diffusion plant, new plants D-3, D-4, D-5, and others were built. At the end of 1955, the D-1 plant was dismantled due to its uneconomical operation and low capacity [4, p. 49]. From 1949 to 1964, three more diffusion plants for uranium enrichment were built: in Tomsk-7 at the

Постановление СМ СССР № 4964-2148сс/оп
«О награждении и премировании за выдающиеся научные работы в области использования атомной энергии, за создание новых видов изделий РДС, достижения в области производства плутония и урана-235 и развития сырьевой базы для атомной промышленности»

г. Москва, Кремль 6 декабря 1951 г.
Сов. секретно
(Особая папка)

III. ***За разработку и промышленное освоение производства урана-235 методом газовой диффузии***:

13. Представить Кикоина Исаака Кушелевича, члена-корреспондента Академии наук СССР, научного руководителя работ, к присвоению звания Героя Социалистического Труда, премировать его суммой 500 тыс. руб. и автомашиной «ЗИМ».

Присвоить Кикоину И.К., члену-корреспонденту Академии наук СССР, звание лауреата Сталинской премии первой степени.

Построить за счет государства и передать в собственность Кикоина И.К., члена-корреспондента Академии наук СССР, дачу с обстановкой.

Установить Кикоину И.К., члену-корреспонденту Академии наук СССР, двойной оклад жалования на все время его работы в области использования *атомной энергии*.

14. Ведущим руководителям работ по разделению *изотопов урана диффузионным* методом Соболеву Сергею Львовичу, академику, Якутовичу Михаилу Васильевичу, кандидату физико-математических наук, Карпачеву Сергею Васильевичу, доктору химических наук, Симоненко Данилу Лукичу, кандидату физико-математических наук, Миллионщикову Михаилу Дмитриевичу, доктору технических наук, Смородинскому Якову Абрамовичу, кандидату физико-математических наук, Обухову Владимиру Семеновичу, научному сотруднику, присвоить звание лауреатов Сталинской премии первой степени.

Премировать тт. Соболева С.Л., Якутовича М.В., Карпачева С.В., Симоненко Д.Л., Миллионщикова М.Д., Смородинского Я.А. и Обухова В.С. суммой 250 тыс. руб. (на всех).

Представить т. Соболева С.Л. к присвоению звания Героя Социалистического Труда, а тт. Якутовича М.В., Карпачева С.В., Смородинского Я.А., Миллионщикова М.Д., Симоненко Д.Л. и Обухова В.С. — к награждению орденом Ленина.

Resolution of the USSR Council of Ministers No. 4964-2148ss/op
"On awarding and rewarding outstanding scientific work in the field of atomic energy use, for the creation of new types of RDS products, achievements in the field of plutonium and uranium-235 production, and the development of a raw material base for the atomic industry"

Moscow, Kremlin December 6, 1951
Top Secret
(Special Folder)

III. *For the development and industrial implementation of uranium-235 production by the gaseous diffusion method*:

13. To recommend Isaak Kushelevich Kikoin, corresponding member of the USSR Academy of Sciences, scientific director of the work, for the title of Hero of Socialist Labor, and to award him 500 thousand rubles and a ZIM car.

To award I K Kikoin, corresponding member of the USSR Academy of Sciences, the title of laureate of the Stalin Prize of the first degree.

To build at the expense of the state and transfer to the ownership of I K Kikoin, corresponding member of the USSR Academy of Sciences, a dacha with furnishings.

To establish for I K Kikoin, corresponding member of the USSR Academy of Sciences, a double salary for the entire period of his work in the field of using atomic energy.

14. To award the leading supervisors of work on separating uranium isotopes by the diffusion method (Academician Sergei L'vovich Sobolev, Candidate of Physical and Mathematical Sciences Mikhail Vasil'evich Yakutovich, Doctor of Chemical Sciences Sergei Vasilyevich Karpachev, Candidate of Physical and Mathematical Sciences Danil Lukich Simonenko, Doctor of Technical Sciences Mikhail Dmitrievich Millionshchikov, Candidate of Physical and Mathematical Sciences Yakov Abramovich Smorodinsky, Research Associate Vladimir Semenovich Obukhov) the title of laureates of the Stalin Prize of the first degree.

Award comrades Sobolev S L, Yakutovich M V, Karpachev S V, Simonenko D L, Millionshchikov M D, Smorodinsky Ya A, and Obukhov V S the sum of 250 thousand rubles (for all).

Nominate comrade Sobolev S L for the title of Hero of Socialist Labor, and comrades Yakutovich M V, Karpachev S V, Smorodinsky Ya A, Millionshchikov M D, Simonenko D L, and Obukhov V S for the Order of Lenin.

Resolution of the USSR Council of Ministers No. 4964-2148ss/op of December 6, 1951 (Strictly confidential/special folder).
"On awarding and rewarding outstanding scientific work in the field of atomic energy use, for the creation of new types of RDS products, achievements in the field of plutonium and uranium-235 production, and the development of a raw material base for the atomic industry."
The USSR Atomic Project: documents and materials (excerpt) [64].

Siberian Chemical Combine, in Angarsk at the Electrolysis Chemical Combine, and in Krasnoyarsk-45 at the Electrochemical Combine. "D L Simonenko was the chair of the State Acceptance Committee for Gas Diffusion Plants (1949–1956)" [61, p. 120].

15. Centrifuge technology for uranium enrichment

Gaseous diffusion technology for uranium enrichment reached its peak, meeting all the Soviet Union's needs for uranium-235. But, sooner or later, technologies replace each other: *gradually, gaseous diffusion stages at plants were stopped and dismantled, and cascades of gas centrifuges were installed in their place. The last gaseous diffusion cascade was stopped in 1991* [4, p. 54]. The stage of centrifuge separation of uranium isotopes began much earlier, and so the plant using centrifuge enrichment technology was brought to full capacity in 1964 [65, p. 22], but this was preceded by a decade of hard work on the development of this method.

In the spring of 1954, Academician I K Kikoin was appointed scientific director for the development of industrial centrifuge technology, and in the next 10 years this difficult task was successfully accomplished. Many of the above-mentioned scientists took direct part in solving this problem and were given state awards. Here is how P E Suetin recalls the initiation of work on the development of industrial centrifuge technology: *In November 1952, we were all accepted into post-graduate school at the Department of Thermal Control Devices (headed by I K Kikoin) at the Laboratory of Measuring Devices of the USSR Academy of Sciences (Moscow). ...The problem of gaseous diffusion separation of uranium isotopes was solved in scientific terms, and under his scientific supervision, near-scientific production and semi-production tasks were successfully accomplished by the laboratory at the diffusion plant in Verkh-Neyvinsky. So, the laboratory was faced with the problem of what to do next. There was serious talk about developing an atomic engine for an airplane, as well as centrifuge separation of isotopes and other problems close to the problem of isotope separation. In the end, the centrifuge method of isotope separation won, since there appeared an idea of organizing a cascade of machines not only inside counter-current centrifuges but primarily outside them, according to a method already proven in diffusion production* [52, p. 92]. The importance of the transition to a new separation method can be demonstrated by two facts. Fact 1:

Isaak Konstantinovich Kikoin.

The World Nuclear Association claims that, at the height of the Cold War, three US gaseous diffusion plants at their peak consumed 7% of all electricity produced in the US at that time [66]. Fact 2: The experimental centrifuge plant of the Ural Electrochemical Combine in 1958 "reached the design regime and showed that, with this method, energy consumption per unit of separation is reduced by at least twenty times (!)" compared to the gaseous diffusion method of separating uranium isotopes [65, p. 10].

The Technology Readiness Level (TRL) scale developed by the US National Aeronautics and Space Administration (NASA) has nine gradation levels. The article "Gas centrifuges for isotope separation. Part 4" [40] states that the development of Lange's centrifuge overcame the first two stages (concept, model), and the development of Steenbeck's centrifuge reached the third stage (laboratory sample). These developments were not in vain: only when discussing the experience gained and examining the shortcomings of the designs of these centrifuges was it possible to develop a modern concept of the centrifuge. I will give two examples that characterize that the work begun by F Lange and D L Simonenko was not in vain. The experiments with Lange's centrifuge *in Sverdlovsk* (*1943–1944*) *resulted in the development of an original installation — a self-cascading counter-current column for separating gas mixtures and isotopes. The idea for its design came to the experimenters when they were trying to determine the causes of the recorded effect of* '*spontaneous*' *separation of a gas mixture in a stationary centrifuge. By March 1945, F Lange and D L Simonenko had conducted a number of successful experiments with a counter-current column. This was the end of their joint work. F Lange was transferred to Moscow, where he headed Laboratory No. 4 at the First Chief Directorate. In 1956, he left for the German Democratic Republic. In 1945, D L Simonenko was transferred to Moscow to Sector No. 2 of Laboratory No. 2 of the USSR Academy of Sciences, headed by I K Kikoin. Here, D L Simonenko continued his work on a counter-current diffusion column*" [67, p. 441]. The idea of counter-current found further application in the development of centrifuges, allowing them to be cascaded. Here is how O D Simonenko writes about the results obtained in the experiments of F Lange and D L Simonenko: *Nevertheless, the experimentally obtained physical information about a drastic change in both the magnitude and direction of circulation under the influence of stationary gas outlet tubes introduced into the compacted part of the gas near the inner surface of the walls of the rotating rotor found application in 1950–1954. At the suggestion of I K Kikoin, the effect of braking the oncoming gas flow was used in vertical centrifuges with a short rigid thin-walled rotor, the idea of creating which was put forward by Evgenii Mikhailovich Kamenev* (*1910–1963*). *This ensured the emergence of counter-current circulation inside the rotor and made it possible to implement the flow of gas through inter-machine communications, that is, cascading of centrifuges* [67, p. 441].

16. Development of methods for recording nuclear explosions

I would like to dwell on one more problem that arose for the participants in the Atomic Project. In early 1954, work on centrifuges at Laboratory No. 2 of the USSR Academy of Sciences slowed down somewhat, because Kurchatov issued an urgent order to Kikoin's department to develop methods for registering nuclear explosions. On November 1, 1952, the USA detonated the world's first thermonuclear charge using the Teller–Ulam scheme at Enewetak atoll. At that time, the USSR was also developing a thermonuclear bomb. Let us turn to G Gorelik's article [68], which reports that Soviet scientists *decided to compare the American* '*product*' *with their own by collecting the* '*fragments*' *of the explosion that entered the atmosphere. They collected freshly fallen snow, hoping to isolate from it the characteristic isotopes formed during the nuclear explosion, but the hope was not justified — the sensitivity of the devices was not sufficient, that is, the experimenters were not skilled enough* (*only a year later, systematic research into the detection of distant nuclear explosions began in the USSR*). Beginning in 1951, the first domestic studies of the possibilities of long-range detection of nuclear explosions began. I K Kikoin headed the work on the development of methods and means for selecting radioactive products of nuclear explosions, as well as highly sensitive installations for measuring the activity of the collected samples. His loyal associates, who had worked with him back in Sverdlovsk, were also involved in this research. Soon, this difficult task was successfully solved, and, as a result, a system for detecting nuclear and thermonuclear explosions was developed. "Sampling of the air by sounding aircraft and their radiochemical analysis made it possible to determine the nuclear fuel and some structural materials of nuclear charges" [69, p. 245]. In his book *The system of early warning of nuclear explosions and the Soviet Atomic Project*, A P Vasil'ev wrote, *In 1957, at the Institute of Atomic Energy, under the scientific supervision of Academician I K Kikoin, a two-volume work entitled* '*Development of a system for detecting nuclear explosions at long distances*' *was completed. This work, with the results of theoretical and experimental studies of methods for registering nuclear explosions and a summary of the experience of research and implementation of technical means of long-range detection at observation points, was awarded the Lenin Prize in the competition of classified works in science and technology for 1958. The author's collective included seven representatives from the Institute of Atomic Energy* [*I K Kikoin* (*scientific supervisor*), *K I Balashov, S A Baranov, V S Obukhov, D L Simonenko, V V Sokol'skii, and Yu I Shcherbina*], *two representatives from the Special Surveillance Service of the Ministry of Defense* (*A I Ustyumenko and V I Lebedev*), *and one representative from the Institute of Physics of the Earth* (*I P Pasechnik*). The contribution of V S Obukhov and D L Simonenko's involvement in this work can be judged by the fact that the first representative of the USSR in the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) from 1955 (the year of its founding) to 1959 was V S Obukhov, and from 1959 to 1961, D L Simonenko.

17. Sergei Konstantinovich Sidorov

Sergei Konstantinovich Sidorov was head of the Phase Transformation Laboratory at the Institute of Metal Physics in 1947–1949. In her article "Sketches of Sergei Konstantinovich Sidorov's portrait," T S Prekul — S K Sidorov's daughter — wrote, *In 1949, our family's life changed dramatically. Against his own will, by a personal decree of the USSR Council of Ministers, dad, together with P A Khalileev, M V Yakutovich, and S V Karpachev, was sent to work at the Ural base of Glavstroy, which was at that time the name of P.O. Box 318 of the Ministry of Medium Machine Building of the USSR*

S K Sidorov in the army in 1940.

Sergei Konstantinovich Sidorov.

(*Novouralsk*), *as the head of the technological sector. As is now known, this sector was engaged in the development and improvement of gas diffusion and centrifuge methods for separating uranium isotopes* [70, p. 262]. In 1953, S K Sidorov was transferred and promoted to a plant for the production of highly enriched uranium-235 and plutonium-239, with the plant being built near the city of Tomsk. T S Prekul recalls, *The established way of life and warm companionship were all gone in 1953. By the decree of the Ministry of Medium Machine Building of the USSR, dad was transferred to the city of Tomsk-7* (*Seversk*) *to the position of scientific director of the Siberian Chemical Plant, enterprise P.O. Box 153. For mom, this was a tragedy. She was very upset by the separation from her loved ones, relatives, and friends. The construction of the new town was just beginning* [70, p. 263]. The construction of Combine No. 816 (JSC Siberian Chemical Plant) in the city of Seversk (Tomsk-7) was discussed in the report "On the progress of fulfilling the tasks for 1951 and on the program of work on the development of the atomic industry in 1951–1955" (November 16, 1951) to I V Stalin. The report was signed by L P Beria, B L Vannikov, A P Zavenyagin, I V Kurchatov, Yu B Khariton, and K I Shchelkin [54, p. 348]. *To provide the tritium plant with uranium-235 enriched to* 1.5–2%, *two diffusion plants are being built as part of Combine No. 816. In addition, two chemical plants and power plants with a capacity of 200 thousand kilowatts will be built at the combine*. For his contribution to the construction and launch of the plant, in 1960 Sergei Konstantinovich was honored with the Lenin Prize "for participation in work on the radical improvement of production."

18. Researchers at Phase Transformation Laboratory of Institute of Metal Physics

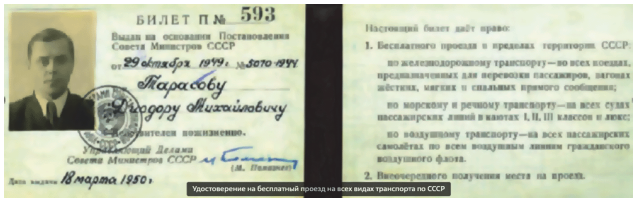
In this paper, an attempt is made to describe the most notable contributions of the scientists of the Institute of Metal Physics to the Atomic Project. Obviously, not all the names of the researchers are mentioned here, since for many years the activities related to the Atomic Project were classified, and after 80 years some information was lost. Only fragmentary mentions of some of them have survived. I will add background information about fellow researchers at the Phase Transformation Laboratory at the Institute of Metal Physics, which was headed by A P Komar from 1933 to 1948: *After the war, N N Buinov took part in the Atomic Project together with the laboratory researchers who subsequently left for closed cities* (*D M Tarasov went to Arzamas, and S K Sidorov left for to Verkh-Neyvinsky*). *Together with other colleagues of A P Komar, he developed for the atomic industry filters for separating radioactive isotopes. Methods of X-ray spectral chemical analysis of the composition of different ores were developed and applied* [71, p. 334].

In 1947, Nikolai Nikolaevich Buinov headed the electron microscopy group founded on the initiative of A P Komar at the institute [71, p. 335] (in 1946, one of the first two EMI-2 transmission electron microscopes purchased in the USA was allocated to the Institute). As it seems to me, such generosity is explained, among other things, by the need to study the structure of the fabricated "filters for separating radioactive isotopes."

Nikolai Nikolaevich Buinov.

N N Buinov in front of institute's first electron microscope EMI-2, 1947.

Diodor Mikhailovich Tarasov.



БИЛЕТ П № 593

Выдан на основании Постановления Совета Министров СССР от 29 октября 1949 г. № 3070-1441

Тарасову Диодору Михайловичу

Удостоверение понижению.

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Date of issue March 18, 1950

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2. Priority receipt of a seat for travel.

D M Tarasov's certificate entitling him to free travel on all types of transport, 1950. https://www.biblioatom.ru/persons/tarasov_diodor_mikhailovich/#gallery.

In the Atomic Project, Diodor Mikhailovich Tarasov participated in the development and assimilation of methods for studying shock and detonation waves. *In addition to pulsed X-ray installations, at that time we had only a modified Dautrich method and photochronographs with a scanning speed of up to 100 meters per second. High-speed oscilloscopes and photochronographs were still being developed* [59, p. 96]. He was awarded the Stalin Prize of the third degree for the development of new methods of ultra-high-speed radiography for studying the central part of the atomic bomb charge (1949) and the Stalin Prize of the second degree for the development of the kinematics and dynamics of explosive compression applied to the RDS-6s and RDS-5 products (1953). He was also decorated with the Order of the Red Banner of Labor for testing the most powerful thermonuclear bomb in the world, also knows as AN602 (1962), and two Orders of Lenin (1949 and 1956) for participation in the development of a new type of RDS-37 thermonuclear charge [72].

Researcher of the Phase Transformations Laboratory in 1945. From right to left are shown sitting M A Manakova, N N Buinov, A P Komar, N V Volkenshtein, M A Blokhin, and an unidentified person; S K Sidorov (standing).

From 1937 to 1946, D M Tarasov worked in the Phase Transformation Laboratory of the Ural Physico-Technical Institute (Institute of Metal Physics of the Ural Branch of RAS) (September 1941–July 1945 service in the Soviet Army). From April 1938, D M Tarasov was a postgraduate student of A P Komar in the specialty "X-ray physics and X-ray structural analysis." In 1946, he was seconded to the First Chief Directorate under the Council of Ministers of the USSR to staff P.O. Box 975, Sarov, founded April 9, 1946 (Laboratory No. 2 of the USSR Academy of Sciences, which received the name KB-11, now RFNC–VNIIEF) with a recommendation "for a research worker in radiography" [73, p. 75]. From December 1947, he worked in the laboratory of X-ray Studies of Explosive Processes headed by V A Tsukerman, and developed high-speed methods of X-ray imaging of fast processes. *The adjective 'first' in relation*

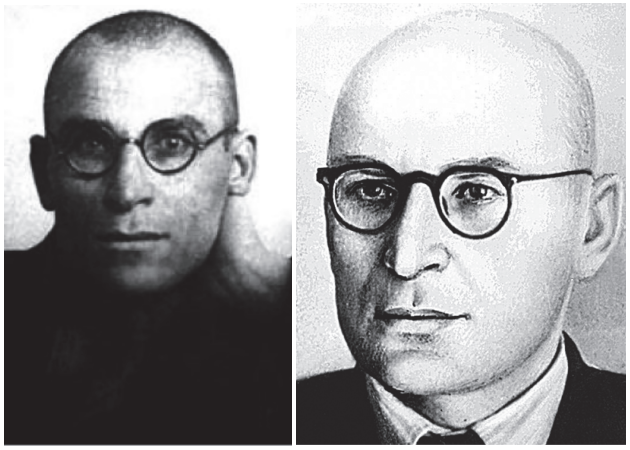
First row, from left to right are shown N V Volkenshtein, S K Sidorov, and N N Buinov; second row, M A Manakova and an unidentified person (1947).

to him can be repeated at least three times: *the first research fellow, the first leader of explosive X-ray experiments at the sites, and the first director and organizer of the branch of the Moscow Engineering Physics Institute* [59, p. 97]. This is how the 'explosive X-ray experiments' began in 1947: *Two weeks before our arrival, the forms were removed from a large reinforced concrete 'barrel' on the same forest site, intended for experimental explosions of charges weighing 1–2 kg. In May of the same year, D M Tarasov carried out the first experimental explosion in this barrel* [58, p. 48]. Thus, in 1947, he obtained the first data on the compressibility of metals.

The next problem that needed to be solved was to obtain data on the convergence and focusing of shock blast waves, since it was necessary to produce a spherically converging shock blast wave to initiate a nuclear bomb. The developers were also interested in many other physical characteristics of the processes occurring during the explosion of a nuclear bomb. The group in which Diodor Mikhailovich worked received answers to these questions. In 1948, D M Tarasov's group was transformed into an independent department, the main task of which was to study compressibility using the X-ray method [59, p. 97].

Boris Vasil'evich Litvinov, academician of the Russian Academy of Sciences and chief designer of NII-1011 (Zababakhin All-Russia Research Institute of Technical Physics, Snezhinsk) dedicated a chapter "Teacher (about D M Tarasov)" to Diodor Mikhailovich Tarasov in his book *Facets of the past* (*triptych*) [74, p. 478].

Anton Panteleimonovich Komar was a researcher at the Institute of Metal Physics in Sverdlovsk from its foundation in 1932 until 1947. In 1946, in Sverdlovsk, together with his colleagues, he launched the first betatron in the USSR. In 1951, he was awarded the Stalin Prize of the second degree for his participation in the development of the project, the manufacture of equipment, and the launch of the synchrotron. This is what he himself writes in his autobiography: *After the war, from 1945 to 1948, I began to work on cyclic electron accelerators and X-ray spectroscopic analysis of special ores. Work on accelerators was continued at the P N Lebedev Physical Institute of the USSR Academy of Sciences, where I was transferred in 1948 by the decision of the Presidium of the USSR Academy of Sciences.* A scan of A P Komar's autobiography is placed on the stand "Anton Panteleimonovich Komar" at the High Energy Physics Department of the National Research Center Kurchatov Institute [75]. In 1948, he was elected a full member of the Academy of Sciences of the Ukrainian Soviet Socialist Republic and transferred to Moscow to the position of deputy director of the P N Lebedev Physical Institute of the USSR Academy of Sciences (1948–1950); from 1950 to 1957, he was director of the Leningrad Physical-Technical Institute [76]. *His name is also associated with the construction of the nuclear research center in Gatchina, where in 1963 he organized and headed one of the largest high-energy physics laboratories at the Leningrad Physical-Technical Institute* (*1963–1976*) [77, p. 394]. A P Komar was the head of the sector for studying the mechanism of phase transformations [later the Department of Phase Transformations and X-Ray Analysis) from the moment of the formation of the Ural Physico-Technical Institute. Graduate student V S Obukhov was initially enrolled in this sector and they even published a joint paper [Komar A R, Obukhoff W S *Sov. Phys.* **5** 4 635 (1934)].



Anton Panteleimonovich Komar.

19. Involvement in Atomic Project work without transfer from main workplace and relations with Ural Polytechnic Institute

The present paper dwells on scientists from the Institute of Metal Physics (IMP) who were transferred from the institute to organizations of the created atomic complex of the USSR, but there were quite a lot of people who were involved in work related to the Atomic Project without being transferred to institutions ensuring its implementation. Thus, Yurii Pavlovich Irkhin, Doctor of Physical and Mathematical Sciences, a theoretical physicist who joined the IMP in 1953 after graduating from Saratov University, recalled that the theoretical department of the institute was then involved in calculations related to nuclear topics (from the memoirs of his student E V Rosenfeld). At the Ural Polytechnic Institute (UPI), as well as at the IMP, filters for diffusion machines were developed, and work was underway to study these filters. The Soviet atomic industry needed thousands of specialists in physics engineering, who had to be taken from somewhere. In the main scientific centers of the country, students were trained in the created physical and technical specialties; thus, in September 1949, the physical and technical faculty was set up at the UPI. The best students who completed the 4th year of the Energy Faculty (20 people) and the Metallurgical Faculty (50 people) were transferred to it. P E Suetin recalled, *The curriculum was apparently drawn up by Professor S V Vonsovsky at the time. He also invited lecturers from among the research staff of the Institute of Metal Physics of the Ural Branch of the Academy of Sciences. ...In the second semester, we were sent for practical training to the IPM to install one of the first particle accelerators — a betatron — in the Urals and in the country. After completing the years of study in the Physics and Technology Department, in the fall, we were sent to write and defend our diplomas. Part of the group was sent to the Ural Branch of the Academy of Sciences to complete the installation and adjustment of the betatron, and V I Akimov, S A Bazhenov, R G Vaganov, N A Plotnikov, V M Ryzhkov, G V Solov'ev, and P E Suetin were sent to the I V Kurchatov Institute of Atomic Energy*. On May 16, 1951, the defense of diploma theses took place in I K Kikoin's office. After the defense of our diploma theses, *the three of us* (*G V Solov'ev, V M Ryzhkov, and I*) *were sent to the Physics and Technology Department of the UPI, and the rest were sent to the diffusion plant in Sverdlovsk-44* (*Verkh-Neyvinsky*). *The diploma students from the Ural Branch of the Academy of Sciences*

were sent to Sverdlovsk-45 (*Nizhnyaya Tura*) *for electromagnetic separation of isotopes, and one graduate was sent to the city of Elektrostal to a plant producing porous partitions* (*N A Plotnikov*) [52, p. 85]. Parigory Evstafievich Suetin, studying at the Physics and Technology Department of the UPI, defended his diploma in 1951 under the supervision of V S Obukhov, and then his PhD dissertation under the supervision of Evgeny Mikhailovich Kamenev in 1955 at the Kurchatov Institute of Atomic Energy. P E Suetin was the rector of Ural University from 1976 to 1993.

The UPI and IMP are located a stone's throw from each other, and researchers from these institutes often combined work or did joint work. Thus, the Kikoins not only worked at the IMP, but also taught at the UPI. All this is recalled with gratitude; for example, the Ural Federal University holds an annual competition of research work of schoolchildren in memory of A K Kikoin and I K Kikoin. F Lange, who worked in the Laboratory of Electrical Phenomena at the Institute of Metal Science, Metal Physics, and Metallurgy of the Ural Branch of the USSR Academy of Sciences (one of the names of the IMP), which was headed by I K Kikoin, while being listed as a senior research fellow at Laboratory No. 2 in Moscow from July 1943 to December 1945, simultaneously taught at the S M Kirov Ural Industrial Institute, being a professor in the High Voltage Engineering Department [78, p. 205]. I will quote the autobiography of D L Simonenko: *In 1938, I went to work at the Ural Physico-Technical Institute, now the Ural Branch of the USSR Academy of Sciences. There, I work as a senior research fellow in the Laboratory of Electrical Phenomena, headed by Corresponding Member of the USSR Academy of Sciences, Professor I K Kikoin. Since 1938, I have been teaching physics at the S M Kirov Ural Industrial Institute, where I am an associate professor in the Physics Department* [79, p. 294]. V S Obukhov led "*pedagogical work at the Ural Industrial Institute*" [80]. A P Komar was the head of the Phase Transformation Laboratory at the Ural Physico-Technical Institute in 1936–1947, and simultaneously, in 1937–1947, he headed the Departments of X-ray Structural Analysis and the X-ray Laboratory, which he founded at Ural State University [62, p. 391]. S V Karpachev (director of the Institute of Metal Physics from 1948 to 1949), having worked on the Atomic Project from 1949 to 1956, was a rector at Ural State University from 1956 to 1963 (Ural State University is now part of Ural Federal University), a director of the Institute of Electrochemistry of the Ural Scientific Center of the USSR Academy of Sciences from 1963 to 1984, and a corresponding member of the USSR Academy of Sciences since 1970.

20. Scientists/chemists

Chemists Yurii Viktorovich Karyakin and Boris Nikolaevich Lundin were the "second-wave researchers" at the Ural Electrochemical Combine, apparently at the invitation of I K Kikoin. In her memoirs, T S Prekul — S K Sidorov's daughter — wrote about life in the city of Novouralsk (Verkh-Neyvinsky), "*The close company of my parents included the families of P A Khalileev, B N Lundin, and Yu V Karyakin. Yurii Vladimirovich was dad's cousin*" (here, apparently, there is a typo: the correct version is Yurii Viktorovich Karyakin) [70, p. 262].

From the memoirs of Vladimir Vladimirovich Volkov, a 1956 graduate of the Physics and Technology Department of the UPI, who defended his diploma thesis at the Ural Base of Technical Supply of the USSR Main Construction Directorate in Department No. 16 in Sverdlovsk-44: "*my diploma work was supervised by Professors Yurii Viktorovich Karyakin and Boris Nikolaevich Lundin*" [80].

Yurii Viktorovich Karyakin was the organizer and first head of the Department of Physicochemical Methods of Analysis at the Physics and Technology Faculty of the UPI. From 1949 to 1963, he worked at the Ural Electrochemical Combine (Novouralsk, Sverdlovsk oblast) as head of the chemical sector, head of the chemical analytical laboratory that he founded at the Central Plant Laboratory, and, from 1956, head of the Central Plant Laboratory. He supervised work on obtaining pure uranium products and highly enriched uranium metal. In 1951, he was awarded the Stalin Prize of the second degree "*for the development of methods for combating corrosion at the diffusion plant*" [64, p. 357]. He was given the award as part of a team headed by Academician Alexander Naumovich Frumkin, who was attracted to the Atomic Project precisely because of the aforementioned failure to "*put into operation the first diffusion plant D-1.*"

Boris Nikolaevich Lundin undertook postgraduate training at the Department of Organic Chemistry of the UPI in 1936 and "*was enrolled part-time as a junior research fellow at the Ural Branch of the Academy of Sciences.*" In 1939, he defended his candidate's dissertation under the supervision of I Ya Postovskii [82, p. 41].

"*The creation of a special lubricant for compressor bearings that is resistant to fluorine-containing environments, nonhygroscopic, and chemically stable*" was a very important and difficult task. To solve it, two organizations were involved: Research Institute-42 (NII-42) of the USSR Ministry of the Chemical Industry and the Ural Polytechnic Institute (headed by Doctor of Engineering Sciences I Ya Postovskii and Candidate of Engineering Sciences B N Lundin). NII-42 created the 'extra' lubricant, but its production in 1948 was very expensive, approximately 1 million rubles per kg. *At the beginning of 1947, a report was published in the American press about the production of inert lubricants by vapor-phase fluorination of various petroleum oils with cobalt trifluoride. The Ural Polytechnic Institute checked this data and synthesized a special organofluorine lubricant called 'UPI' oil,* which was put into production in 1948 [61, p. 116]. *For the creation of the UPI oil, its introduction into production, and solving a number of issues related to its operation, I Ya Postovskii and B N Lundin were awarded the Stalin Prize of the second degree in 1951* [61, p. 116] *...for the development of the technology for the production of uranium hexafluoride and new types of lubricating oils that are stable in a uranium hexafluoride environment* [64, p. 358]. The creation of *a special fluorinated UPI lubricant* (*named after the place of its creation, i.e., the Ural Polytechnic Institute*), *operating in a uranium hexafluoride environment, opened up the possibility of designing simpler-to-manufacture single-stage diffusion machines* [4, p. 23].

21. Instead of an epilogue

In the report (On the progress of fulfilling assignments for 1951 and on the work program for the development of the atomic industry in 1951–1955) of November 16, 1951 to I V Stalin, signed by L P Beria, B L Vannikov, A P Zavenyagin, I V Kurchatov, Yu B Khariton, and K I Shchelkin [54,

p. 347], some results are conveyed characterizing the complexity of the task of producing uranium-235: *Production of uranium-235 by the diffusion method was one of the most complex tasks. Work on the problem of producing uranium-235 by the diffusion method began in 1946 with the development of machines with a capacity of 8 grams per second. Scientists, designers, and engineers had to construct several types of complex diffusion machines, completely sealed and operating continuously in a deep vacuum. It was also necessary to find corrosion-resistant materials for these machines that would not be affected by the highly active chemical working gas — a compound of uranium with fluorine. The extensive work carried out over the past years by physicists, chemists, and designers made it possible to organize the industrial production of diffusion machines with a capacity of 1200 and 2200 grams per second in 1951, which ensured a significant increase in the production of uranium-235.* An even more difficult task was to produce uranium by centrifugation. If, when developing diffusion machines, it was possible to rely on results from the USA and Great Britain, then the development of the centrifuge separation method was several decades ahead of the world nuclear industry.

A reason for writing this paper was the 90th anniversary of the M N Mikheev Institute of Metal Physics, founded in 1932. The IPM celebrated its anniversary (90 years) at the end of 2022. There were also anniversaries in 2023 — 80 years since the IPM was involved in the work on the Atomic Project in 1943 and 80 years since the construction of the first centrifuge based on Lange's invention in the USSR. The years 2023 and 2024 have two memorable dates associated with Isaak Konstantinovich Kikoin (March 28, 1908–December 28, 1984): 115 years since his birth and 40 years since his death [82]. Also, 80 years ago, in 1943, Laboratory No. 2 of the USSR Academy of Sciences [82] was founded (now the National Research Center Kurchatov Institute). However, this paper is being published on the eve of the 75th anniversary of the first nuclear explosion in the USSR (August 29, 1949), which put an end to the US monopoly on the possession of nuclear weapons.

The author dedicates this paper to the selfless work of the creators of the nuclear shield of our Motherland.

Acknowledgments. The author thanks S V Gudina, I Yu Arapova, M M Nasryeva, V P Spirina, and N I Nosal'skaya for their assistance in preparing and editing the paper, as well as for valuable comments and ideas expressed during its discussion. The work was performed within the framework of the State Assignment of the Ministry of Education and Science (theme: Quantum, No. 122021000038-7).

22. Appendix

22.1 Historical background

The institutes, universities, and cities mentioned in the paper had different names in different years, and to avoid confusion, the main ones are listed in this section.

From its foundation in 1932 to 1939, the Institute of Metal Physics was called the Ural Physico-Technical Institute (UralPTI); from 1939 to 1943, the Institute of Metal Physics, Metal Science, and Metallurgy as part of the Ural Branch of the USSR Academy of Sciences; from 1943 to 1945, the Institute of Metal Physics and Metallurgy of the Ural Branch of the USSR Academy of Sciences; and beginning in 1945, the Institute of Metal Physics of the Ural Branch of the USSR Academy of Sciences.

The city of Ekaterinburg was called Sverdlovsk from 1924 to 1991.

The city of Novouralsk (Sverdlovsk-44 from 1954 to 1994) is a city in the Sverdlovsk oblast, a closed administrative-territorial entity located next to the village of Verkh-Neyvinsky.

The city of Seversk (former names Post Office Box No. 5, Berezki, Tomsk-7) is a city in the Tomsk oblast, a closed administrative-territorial entity.

Ural Federal University (UrFU) in Yekaterinburg was called Ural State University from its foundation in 1920 until 1925. In 1925, it was renamed the Ural Polytechnic Institute (UPI). In 1930, the faculties of UPI were transformed into higher technical universities. In 1931, Sverdlovsk State University (SSU) was separated (revived) from some of the higher technical universities. In 1934, the Ural Industrial Institute (UII) was founded on the basis of the higher technical universities remaining from the UPI that were not included in the SSU. In 1945, the SSU was renamed Ural State University (USU). In 1948, UII was renamed Ural Polytechnic Institute. In 1992, the UPI was renamed Ural State Technical University (USTU-UPI). In 2010, Ural Federal University (UrFU) was founded, uniting USTU-UPI and USU.

22.2 Physical reference data

This section provides information about physical characteristics of uranium and its compounds, as well as about plutonium and uranium bombs.

Natural uranium contains three radioisotopes. The percentage content in natural uranium and its half-life $T_{1/2}$ are given in brackets after the isotope designation: U-234 (0.0055%, $T_{1/2} = 2.45 \times 10^5$ years); U-235 (0.7200%, $T_{1/2} = 7.04 \times 10^8$ years); U-238 (99.2745%, $T_{1/2} = 4.47 \times 10^9$ years); and U-233 is also present in very small quantities [48].

Uranium is a silvery-white metal with a density of 18.95 g cm^{-3} and a melting point 1135 °C. UF_4 and UF_6 uranium tetra- and hexafluorides are important compounds for industry. UF_4 is an intermediate product in the production of metallic uranium. UF_6 is the only uranium compound that is gaseous at a relatively low temperature (boiling point 56 °C and used in the separation of uranium isotopes in gaseous diffusion and centrifuge methods) [49, p. 6].

Nuclear weapons are produced using so-called "weapons-grade plutonium"; this is plutonium, according to the isotopic composition, containing at least 94% of the Pu-239 isotope with a half-life of 24,110 years.

Fat Man was the codename for an atomic bomb developed as part of the Manhattan Project and detonated over the Japanese city of Nagasaki on August 9, 1945 by the United States. It contained a plutonium core weighing about 6.2 kg and had an implosion detonation scheme. The mass of the bomb was 4670 kg. The power of the explosion was 21 kt TNT equivalent (kilotons of trinitrotoluene) [50, p. 10].

Little Boy (uranium charge, nuclear) was detonated over the Japanese city of Hiroshima on August 6, 1945. This was an aviation bomb with a warhead based on 64 kg of uranium and an actual power of 1518 kt TNT. It had a gun-type design, which has a low efficiency. Therefore, the USSR decided not to reproduce this bomb, immediately developing an implosion-type atomic bomb [50, p. 5].

References

1. Tyushevskaya V N *Isaak Konstantinovich Kikoin*: *Stranitsy Zhizni* (Isaak Konstantinovich Kikoin: Pages of Life) (Ser. Creators of the Nuclear Age) (Moscow: IzdAT, 1995); Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/tyushevskaya_kikoin_1995/p0_o/
2. ''No. 128. Rasporyazhenie GKO No. 2352ss. 'Ob organizatsii rabot po uranu.' 28 sentyabrya 1942 g.'' (''No. 128. USSR State Defense Committee order No. GKO-2352ss 'On the organization of works on uranium.' September 28, 1942''), in *Atomnyi Proekt SSSR. Dokumenty i Materialy* (The USSR Atomic Project: Documents and Materials) Vol. 1, Pt. 1 (Comp. L I Kudinova) (Moscow: Nauka, 1998) p. 269; Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/atomny-proekt-sssr_t1_kn1_1998/p269/
3. Khalileev P ''Moi vospominaniya'' (''My memoirs'') *Ural* (3) (2001); electronic version on the website ''Journal Hall:'' https://magazines.gorky.media/ural/2001/3/moi-vospominaniya.html
4. Voinov E M, Plotkina A G ''Razrabotka diffuznogo metoda razdeleniya izotopov urana'' (''Development of the diffusion method for separating uranium isotopes''), in *Kurchatovskii Institut. Istoriya Atomnogo Proekta* (Kurchatov Institute. History of the Atomic Project) Issue 3 (Moscow: Rossiiskii Nauchnyi Tsentr ''Kurchatovskii Institut'', 1995) p. 5; Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/kiae-istoriya-atomnogo-proekta_v3_1995/p5/
5. Kiselev G V ''L D Landau in the Soviet Atomic Project: a documentary study'' *Phys. Usp.* **51** 911 (2008); ''Uchastie L.D. Landau v sovetskom Atomnom proekte (v dokumentakh)'' *Usp. Fiz. Nauk* **178** 947 (2008)
6. Goncharov G A, Ryabev L D ''The development of the first Soviet atomic bomb'' *Phys. Usp.* **44** 71 (2001); ''O sozdanii pervoi otechestvennoi atomnoi bomby'' *Usp. Fiz. Nauk* **171** 79 (2001)
7. Goncharov G A ''The extraordinarily beautiful physical principle of thermonuclear charge design (on the occasion of the 50th anniversary of the test of RDS-37 — the first Soviet two-stage thermonuclear charge)'' *Phys. Usp.* **48** 1187 (2005); ''Neobychainyi po krasote fizicheskii printsip konstruirovaniya termoyadernykh zaryadov (k 50-letiyu so dnya ispytaniya pervogo otechestvennogo dvukhstupenchatogo termoyadernogo zaryada RDS-37)'' *Usp. Fiz. Nauk* **175** 1243 (2005)
8. Kiselev G V ''Moscow State University physics alumni and the Soviet Atomic Project'' *Phys. Usp.* **48** 1251 (2005); ''Fiziki — vypuskniki Moskovskogo universiteta i sovetskii Atomnyi proekt'' *Usp. Fiz. Nauk* **175** 1343 (2005)
9. Kiselev G V, Konev V N ''History of the realization of the thorium regime in the Soviet Atomic Project'' *Phys. Usp.* **50** 1259 (2007); ''Istoriya realizatsii torievogo rezhima v sovetskom Atomnom proekte'' *Usp. Fiz. Nauk* **177** 1361 (2007)
10. Romanov Yu A ''Memoir of the Teacher'' *Phys. Usp.* **39** 179 (1996); ''Vospominanie ob uchitele'' *Usp. Fiz. Nauk* **166** 195 (1996)
11. Shpinel' V S ''Remarks on the paper G A Goncharov and L D Ryabev 'The development of the first Soviet atomic bomb'' *Phys. Usp.* **45** 227 (2002); ''K stat'e G A Goncharova, L D Ryabeva 'O sozdanii pervoi otechestvennoi atomnoi bomby''' *Usp. Fiz. Nauk* **172** 235 (2002)
12. Goncharov G A, Ryabev L D ''"About V S Spinel's remarks on the review 'The development of the first Soviet atomic bomb'" *Phys. Usp.* **45** 228 (2002); ''O zamechaniyakh V.S. Shpinelya k stat'e 'O sozdanii pervoi otechestvennoi atomnoi bomby''' *Usp. Fiz. Nauk* **172** 236 (2002)
13. Khariton Yu B, Adamskii V B, Smirnov Yu N ''On the making of the Soviet hydrogen (thermonuclear) bomb'' *Phys. Usp.* **39** 185 (1996); ''O sozdanii sovetskoi vodorodnoi (termoyadernoi) bomby'' *Usp. Fiz. Nauk* **166** 201 (1996)
14. Gurevich I I, Zel'dovich Ya B, Pomeranchuk I Ya, Khariton Yu B ''Utilization of the nuclear energy of the light elements'' *Sov. Phys. Usp.* **34** 445 (1991); ''Ispol'zovanie yadernoi energii legkikh elementov'' *Usp. Fiz. Nauk* **161** (5) 171 (1991)
15. Goncharov G A ''American and Soviet H-bomb development programmes: historical background'' *Phys. Usp.* **39** 1033 (1996); ''Osnovnye sobytiya istorii sozdaniya vodorodnoi bomby v SSSR i SShA'' *Usp. Fiz. Nauk* **166** 1095 (1996)
16. Goncharov G A ''On the history of creation of the Soviet hydrogen bomb'' *Phys. Usp.* **40** 859 (1997); ''K istorii sozdaniya sovetskoi vodorodnoi bomby'' *Usp. Fiz. Nauk* **167** 903 (1997)
17. Adamskii V B, Smirnov Yu N ''Once again on the creation of the Soviet hydrogen bomb'' *Phys. Usp.* **40** 855 (1997); ''Eshche raz o sozdanii sovetskoi vodorodnoi bomby'' *Usp. Fiz. Nauk* **167** 899 (1997)
18. Kikoin I K, Gubar' S V, Obukhov V S ''Novaya sistema elektroizmeritel'noi apparatury dlya izmereniya postoyannykh tokov bol'shoi sily'' (''New system of electrical measuring equipment for measuring high-power direct currents'') *Vestn. Elektricheskoi Promyshlennosti* (7–8) 5 (1942); in *I K Kikoin — Fizika i Sud'ba* (I K Kikoin — Physics and Destiny) (Ser. Monuments of Russian Science. XX Century, Exec. Ed. S S Yakimov) (Moscow: Nauka, 2008) p. 133; Electronic version on the website ''History of Rosatom. Electronic Library'': https://elib.biblioatom.ru/text/kikoin-fizika-i-sudba_2008/p133/
19. Tyushevskaya V N, in *I K Kikoin*: *Stranitsy Zhizni* (I K Kikoin: Pages of Life) (Moscow: IzdAT, 1995) p. 8; ''I.K. Kikoin'', in *I K Kikoin — Fizika i Sud'ba* (I K Kikoin — Physics and Destiny) (Ser. Monuments of Russian Science. XX Century, Exec. Ed. S S Yakimov) (Moscow: Nauka, 2008) p. 562; Electronic version on the website ''History of Rosatom. Electronic Library'': http://elib.biblioatom.ru/text/kikoin-fizika-i-sudba_2008/p562/
20. ''Kharakteristika ot 15 noyabrya 1942 g. Podpis' Kikoina'' (''Personal file as of November 15, 1942. Signature of Kikoin''), Central Scientific Library of the Ural Branch of the Russian Academy of Sciences. Department of Collections and Information Services. F. 1. Op. 4. D. 1479. Personal file of Obukhov V.S. L. 83
21. ''Rasporyazheniya zasedaniya Prezidiuma AN SSSR ot 2 sentyabrya 1943 g., punkt 26. (Zaverennaya kopiya)'' (''Orders of the meeting of the Presidium of the USSR Academy of Sciences as of September 2, 1943, item 26. (Certified copy)''), Central Scientific Library of the Ural Branch of the Russian Academy of Sciences. Department of Collections and Information Services. F. 1. Op. 4. D. 1479. Personal file of Obukhov V.S. L. 90
22. ''Pis'mo (khodataistvo) ot 16 sentyabrya 1943 g. v komitet po delam Vysshei shkoly SNK SSSR ot direktora Instituta metallofiziki i metallurgii N.V. Demeneva o razreshenii dopustit' Obukhova '...do zashchity kandidatskoi dissertatsii bez kandidatskikh ekzamenov''' (''Letter (petition) as of September 16, 1943 to the Higher Attestation Commission of the Committee for Higher School Affairs under the Council of People's Commissars of the USSR from director of the Institute of Metallophysics, Metallography and Metallurgy N V Demenev on permission to admit Obukhov '...to the defense of his candidate's dissertation without candidate examinations'''), Central Scientific Library of the Ural Branch of the Russian Academy of Sciences. Department of Collections and Information Services. F. 1. Op. 4. D. 1479. Personal file of Obukhov V.S. L. 88 (Institute of Metallophysics, Metallography and Metallurgy is another former name of IMP Ural Branch RAS)
23. Ustinov V V (Ed.-in-Chief), Schastlivtsev V M et al. (Comp.) *Fizika Metallov na Urale. Institut Fiziki Metallov v Gody Velikoi Otechestvennoi Voiny* (Physics of Metals in the Urals. Institute of Metal Physics during the Great Patriotic War) (Ekaterinburg: IFM UrO RAN, 2020)
24. Dorfman Ya G, Kikoin I K *Fizika Metallov* (Physics of Metals) (Leningrad–Moscow: Gos. Tekhn.-Teoretich. Izd., 1933)
25. Kikoin A K ''Brat, uchitel', drug'' (''Brother, teacher, friend''), in *Isaak Konstantinovich Kikoin: Vospominaniya Sovremennikov* (Isaak Konstantinovich Kikoin. Memoirs of Contemporaries) 2nd ed., rev. and enlarg. (Exec. Ed. N N Ponomarev-Stepnoi, Comp. E M Voinov, A G Plotkina) (Moscow: Nauka, 1998) p. 10; Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/kikoin-vospominaniya-sovremennikov_1998/p10/
26. Simonenko D L ''Kratkoe opisanie pervykh eksperimental'nykh rabot po razdeleniyu izotopov urana v SSSR (1942–1948 gg.)'' (''Brief description of the first experimental work on the separation of uranium isotopes in the USSR (1942–1948)''), in *Istoriya*

Sovetskogo Atomnogo Proekta: *Dokumenty, Vospominaniya, Issledovaniya* (History of the Soviet Atomic Project: Documents, Recollections, Investigations) Issue 1 (Moscow: Yanus-K, 1998) p. 135, III. Iz istorii razdeleniya izotopov urana (From history of separation of uranium isotopes); Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/istoriya-sovetskogo-atomnogo-proekta_v1_1998/p135/

27. Sulaberidze G A, Palkin V A, Borisevich V D, Borman V D, Tikhomirov A V *Teoriya Razdeleniya Izotopov v Kaskadakh* (Theory of Isotope Separation in Cascades) (Ed. V D Borman) (Moscow: MIFI, 2007) Manual; Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/teoriya-razdeleniya-izotopov-v-kaskadah_2007/p1/
28. Babaev N S *50 Let pod Grifom ''Sovershenno Sekretno''* (Fifty Years under the Heading ''Strictly Classified'') (Moscow: OOO ''Inform-Znanie,'' 2008); Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/babaev_50-let-sovershenno-sekretno_2008/p0/
29. Smyth H D W *Atomic Energy for Military Purposes*: *The Official Report on the Development of the Atomic Bomb under the Auspices of the United States Government, 1940–1945* (Princeton, NJ: Princeton Univ. Press, 1945); Translated into Russian: *Atomnaya Energiya dlya Voennykh Tselei. Ofitsial'nyi Otchet o Razrabotke Atomnoi Bomby pod Nablyudeniem Pravitel'stva SShA* (Moscow: IzdAT, 2009) p. 209, Ch. XI ''Electromagnitnoe razdelenie izotopov urana'' (''Electromagnetic separation of uranium isotopes''); Electronic version on the website ''History of Rosatom. Electronic Library:'' https: https://elib.biblioatom.ru/text/smit_atomnaya-energiya_2007/p209/
30. Avrorin E N, Litvinov B V, Il'kaev R I, Mikhailov V N ''History of the nuclear weapons industry'' *Atom. Energy* **86** 402 (1999) https://doi.org/10.1007/BF02673191; ''Sozdanie i razvitie yaderno-oruzheinogo kompleksa'' *Atom. Energ.* **86** (6) 431 (1999); Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/atomnaya-energiya_t86-6_1999/p431/
31. ''No. 75. Zayavka na izobretenie V.A. Maslova i V.S. Shpinelya 'Ob ispol'zovanii urana v kachestve vzryvchatogo i otravlyayushchego veshchestva' 17 oktyabrya 1940 g.'' (''No. 75. Claim for an invention from V A Maslov, V S Shpinel, 'About using uranium as an explosive and toxic agent' as of October 17, 1940''), in *Atomnyi Proekt SSSR*: *Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 1 *1938–1945* Pt. 1 (Gen. Ed. L D Ryabev, Exec. Comp. L I Kudinova) (Moscow: Nauka, 1998) p. 193; Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/atomny-proekt-sssr_t1_kn1_1998/p193/
32. ''No. 76. Zayavka na izobretenie F. Lange, V.A. Maslova, V.S. Shpinelya 'Sposob prigotovleniya uranovoi smesi, obogashchennoi uranom s massovym chislom 235. Mnogokamernaya tsenrifuga'. Ne ranee 17 oktyabrya – ne pozdnee 31 dekabrya 1940 g.'' (''No. 76. Claim for an invention from F Lange, V A Maslov, V S Shpinel, 'Method of preparing a uranium mixture enriched in uranium with a mass number of 235. Multi-chamber centrifuge' as of not earlier than October 17 – not later than December 31, 1940''), in *Atomnyi Proekt SSSR*: *Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 1 *1938–1945* Pt. 1 (Gen. Ed. L D Ryabev, Exec. Comp. L I Kudinova) (Moscow: Nauka, 1998) p. 196; Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/atomny-proekt-sssr_t1_kn1_1998/p196/
33. ''No. 85. Zayavka na izobretenie F. Lange i V.A. Maslova 'Termotsirkulyatsionnaya tsentrifuga'. Ne ranee 1 yanvarya — ne pozdnee 3 fevralya 1941 g.'' (''No. 85. Claim for an invention from F Lange, V A Maslov 'Thermocirculation centrifuge' as of not earlier than January 17 — not later than February 3, 1941''), in *Atomnyi Proekt SSSR*: *Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 1 *1938–1945* Pt. 1 (Gen. Ed. L D Ryabev, Exec. Comp. L I Kudinova) (Moscow: Nauka, 1998) p. 213; Electronic version on the website 11History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/atomny-proekt-sssr_t1_kn1_1998/p213/
34. ''No. 164. Zapiska I.V. Kurchatova M.G. Pervukhinu ob ispytaniyakh tsentrifugi. 29 aprelya 1943 g.'' (''No. 164. Memorandum from I V Kurchatov to M G Pervukhin on the centrifuge testing as of April 29, 1943''), in *Atomnyi Proekt SSSR*: *Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 1 *1938–1945* Pt. 1 (Gen. Ed. L D Ryabev, Exec. Comp. L I Kudinova) (Moscow: Nauka, 1998) p. 340; Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/atomny-proekt-sssr_t1_kn1_1998/p340/
35. ''No. 158. Zapiska I.V. Kurchatova M.G. Pervukhinu o neobkhodimosti demobilizatsii V.M. Kel'mana. 1 aprelya 1943 g.'' (''No. 158. Memorandum from I V Kurchatov to M G Pervukhin on the need to demobilize V M Kel'man as of April 1, 1943''), in *Atomnyi Proekt SSSR*: *Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 1 *1938–1945* Pt. 1 (Gen. Ed. L D Ryabev, Exec. Comp. L I Kudinova) (Moscow: Nauka, 1998) p. 328; electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/atomny-proekt-sssr_t1_kn1_1998/p340/
36. ''No. 186a. Otchet I.K. Kikoina I.V. Kurchatovu o rezul'tatakh komandirovki v Sverdlovsk i sostoyanii rabot po tsentrifuge i diffuzionnoi ustanovke. 21 sentyabrya 1943 g.'' (''No. 186a. Report of I K Kikoin to I V Kurchatov on the results of the trip to Sverdlovsk and the state of work on the centrifuge and diffusion plant as of September 21, 1943''), in *Atomnyi Proekt SSSR*: *Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 1 *1938–1945* Pt. 1 (Gen. Ed. L D Ryabev, Exec. Comp. L I Kudinova) (Moscow: Nauka, 1998) p. 391; Electronic version on the website ''History of Rosatom. Electronic Library:'' https//elib.biblioatom.ru/text/atomny-proekt-sssr_t1_kn1_1998/p391/
37. Chikov V *Russkie Nelegaly v SShA* (Russian Illegals in the USA) (Moscow: Eksmo, 2003); Information on the website LiveLib: https://www.livelib.ru/book/1000024627-russkie-nelegaly-v-ssha-vladimir-chikov
38. Khariton Yu B, Smirnov Yu N ''O nekotorykh mifakh i legendakh vokrug sovetskikh atomnogo i vodorodnogo proektov'' (''On some myths and legends around the Soviet Atomic and Hydrogen Projects''), Report delivered on January 12, 1993 at a Session of the Academic Council at the Russian Research Centre ''Kurchatov Institute'' in connection with the 90th anniversary of I V Kurchatov's birth; in *Chelovek Stoletiya*: *Yulii Borisovich Khariton* (Man of the Century: Yulii Borisovich Khariton) (Ed. V N Mikhailov) (Moscow: IzdAT, 1999) p. 124; Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/hariton-chelovek-stoletiya_1999/p124/
39. ''No. 151. Zapiska zaveduyushchego Laboratoriei No. 2 I.V. Kurchatova zamestitelyu predsedatelya SNK SSSR M.G. Pervukhinu s analizom soderzhaniya razvedmaterialov i predlozheniyami k programme rabot. 7 marta 1943 g.'' (''No. 151. Memorandum from I V Kurchatov, the head of Laboratory No. 2, to M G Pervukhin, the deputy chairman of the Council of People's Commissars of the USSR, with an analysis of the content of intelligence materials and proposals for the work program as of March 7, 1943''), in *Atomnyi Proekt SSSR*: *Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 1 *1938–1945* Pt. 1 (Gen. Ed. L D Ryabev, Exec. Comp. L I Kudinova) (Moscow: Nauka, 1998) p. 391; Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/atomny-proekt-sssr_t1_kn1_1998/p314/
40. Skorynin G M ''Gazovye tsentrifugi dlya razdeleniya izotopov. Chast' 4. Sozdanie v SSSR promyshlennoi tekhnologii obogashcheniya urana tsentrifuzhnym metodom'' (''Gas centrifuges for isotope separation. Part 4. Development of industrial technology for enriching uranium using the centrifuge method in the USSR''), PRoAtom Agency. May 7, 2019, https://www.proatom.ru/modules.php?name=News&sid=8577
41. ''No. 184. Plan raboty Laboratorii No. 2 na vtoroe polugodie 1943 g. 18 avgusta 1943 g. Ob''yasnitel'naya zapiska k planu rabot Laboratorii No. 2 Akademii nauk SSSR na vtoroe polugodie 1943 g.'' (''No. 184. Work plan of Laboratory No. 2 for the second half of 1943 as of August 18, 1943. Explanatory memorandum to the work plan of Laboratory No. 2 of the USSR Academy of Sciences for the second half of 1943''), in *Atomnyi Proekt SSSR*: *Dokumenty*

i Materialy (Soviet Atomic Project: Documents and Materials) Vol. 1 *1938–1945* Pt. 1 (Gen. Ed. L D Ryabev, Exec. Comp. L I Kudinova) (Moscow: Nauka, 1998) p. 386; Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/atomny-proekt-sssr_t1_kn1_1998/p386/

42. Khalileev P A "Ya agent NKVD" ("I'm an NKVD agent") *Vestn. Ural. Otd. Ross. Akad. Nauk* **1** (3) 19 (2003)
43. "No. 390. Doklad I.K. Kikoina 'O razdelenii izotopov urana' na zasedanii Tekhnicheskogo soveta Spetsial'nogo komiteta pri GKO. Ne pozdnee 10 sentyabrya 1945 g." ("No. 390. Report of I K Kikoin 'On the separation of uranium isotopes' at the meeting of the Technical Council of the Special Committee under the State Defense Committee as of not later than September 10, 1945"), in *Atomnyi Proekt SSSR: Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 1 *1938–1945* Pt. 2 (Gen. Ed. L D Ryabev, Exec. Comp. L I Kudinova) (Moscow: Izd. MFTI, 2002) p. 367; Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/atomny-proekt-sssr_t1_kn2_2002/p367/
44. Nasonov V "Blagorodnoe iskusstvo — portit' otnosheniya s nachal'stvom. K stoletiyu so dnya rozhdeniya Fritz'a Lange — nemetskogo uchenogo, rabotavshego nad sozdaniem sovetskoi atomnoi bomby" ("The noble art of spoiling relations with the boss. On the centenary of the birth of Fritz Lange, a German scientist who worked on the creation of the Soviet atomic bomb"), *Nezavisimaya Gazeta* No. 06(42) of June 20, 2001; Archive copy in the online archive of the Internet Archive library (Wayback Machine) as of July 12, 2007, https://web.archive.org/web/20020124164816/http://science.ng.ru/safe/2000-01-19/7_art.html
45. "No. 404. Iz doklada PGU I.V. Stalinu 'O sostoyanii rabot po polucheniyu i ispol'zovaniyu atomnoi energii' 17 yanvarya 1946 g." ("No. 404. Report of the First Main Directorate to I V Stalin 'On the state of work on obtaining and using atomic energy" as of January 17, 1946"), in *Atomnyi Proekt SSSR: Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 1 *1938–1945* Pt. 2 (Gen. Ed. L D Ryabev, Exec. Comp. L I Kudinova) (Moscow: Izd. MFTI, 2002) p. 413; Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/atomny-proekt-sssr_t1_kn2_2002/p413/
46. "Zapiska I.K. Kikoina i A.I. Alikhanova M.G. Pervukhinu 'Sostoyanie problemy razdeleniya izotopov urana' 4 yanvarya 1944 g." ("Memorandum of I K Kikoin and A I Alikhanov to M G Pervukhin 'On the state of the problem of separating uranium isotopes' as of January 4, 1944"), in *Atomnyi Proekt SSSR: Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 1 *1938–1945* Pt. 2 (Gen. Ed. L D Ryabev, Exec. Comp. L I Kudinova) (Moscow: Izd. MFTI, 2002) p. 15; in *I K Kikoin — Fizika i Sud'ba* (I K Kikoin — Physics and Destiny) (Ser. Monuments of Russian Science. XX Century) (Exec. Ed. S S Yakimov) (Moscow: Nauka, 2008) p. 339; Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/kikoin-fizika-i-sudba_2008/p339/
47. "No. 193. Spravka I.V. Kurchatova 'O sostoyanii rabot po probleme na 27 noyabrya s.g.', predstavlennaya M.G. Pervukhinu. 28 noyabrya 1943 g." ("No. 193. Report by I V Kurchatov to M G Pervukhin 'On the state of work on the problem as of November 27 of this year' as of November 28, 1943"), in *Atomnyi Proekt SSSR: Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 1 *1938–1945* Pt. 1 (Gen. Ed. L D Ryabev, Exec. Comp. L I Kudinova) (Moscow: Nauka, 1998) p. 403; Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/atomny-proekt-sssr_t1_kn1_1998/p403/
48. Rakov E G "Uran (khimicheskii element)" ("Uranium (chemical element)"), Scientific and educational portal "Great Russian Encyclopedia," https://bigenc.ru/c/uran-khimicheskii-element-ac6ea2?ysclid=lp5n5k7lap848709125
49. Andreeva O S, Bad'in V I, Kornilov A N *Prirodnyi i Obogashchennyi Uran. Radiatsionno-Gigienicheskie Aspekty* (Natural and Enriched Uranium. Radiation-Hygienic Aspects) (Moscow: Atomizdat, 1979); Electronic version on the website "History of Rosatom. Electronic library:" https://elib.biblioatom.ru/text/andreeva_prirodnyy-i-obogaschennyy-uran_1979/p0/
50. Baranov M I "Antologiya vydayushchikhsya dostizhenii v nauke i tekhnike. Chast' 40: Nauchnoe otkrytie metoda vzryvnoi implozii dlya polucheniya sverkhkriticheskoi massy yadernogo zaryada i ukrainskii 'sled' v amerikanskom atomnom proekte "Mankhetten"" ("Anthology of outstanding achievements in science and technology. Part 40: Scientific discovery of the method of explosive implosion for obtaining a supercritical mass of a nuclear charge and Ukrainian 'trace' in the American Manhattan (Atomic) Project") *Elektrotekh. Elektromekh.* (5) 3 (2017); Electronic version on the website of the Scientific Electronic Library "CyberLeninka:" https://cyberleninka.ru/article/n/antologiya-vydayuschihsya-dostizheniy-v-nauke-i-tehnike-chast-40-nauchnoe-otkrytie-metoda-vzryvnoy-implozii-dlya-polucheniya
51. "No. 253. Postanovlenie SM SSSR No. 1127-402ss/op 'O plane spetsial'nykh nauchno-issledovatel'skikh rabot na 1948 god'. 6 aprelya 1948 g." ("No. 253. Resolution of the USSR Council of Ministers No. 1127-402ss/op 'On the plan of special scientific research work for 1948' as of April 6, 1948"), in *Atomnyi Proekt SSSR: Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 2 *Atomnaya Bomba. 1945–1954* (Atomic Bomb. 1945–1954) Book 3 (Gen. Ed. L D Ryabev, Exec. Comp. G A Goncharov) (Sarov: RFYaTs–VNIIEF, 2002) p. 431; Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/atomny-proekt-sssr_t2_kn3_2002/p431/
52. Suetin P E "U istokov atomnoi problemy. Kak nachinalsya Ural'skii Fiztekh" ("At the origins of the atomic problem. How the Ural Phystech began") *Izv. Ural. Gos. Univ.* (12) 83 (1999); Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/suetin_u-istokov-atomnoy-problemy_1999/p83/
53. Goncharov V V "Pervyi period razvitiya atomnoi energetiki v SSSR" ("The first period of development of nuclear power in the USSR"), in *Istoriya Atomnoi Energetiki Sovetskogo Soyuza i Rossii* (History of Nuclear Power of the Soviet Union and Russia) Issue 1 (Ed. V A Sidorenko) (Moscow: IzdAT, 2001) p. 16; Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/istoriya-atomnoy-energetiki_v1_2001/p16/
54. "No. 135. Doklad L.P. Beriya, B.L. Vannikova, A.P. Zavenyagina, I.V. Kurchatova, Yu.B. Kharitona i K.I. Shchelkina I.V. Stalinu o khode vypolneniya zadanii na 1951 god i o programme rabot po razvitiyu atomnoi promyshlennosti v 1951–1955 gg. 16 noyabrya 1951 g." ("No. 135. Report by L P Beria, B L Vannikov, A P Zavenyagin, I V Kurchatov, Yu B Khariton, and K I Shchelkin to I V Stalin on the progress of fulfilling the tasks for 1951 and on the work program for the development of the nuclear industry in 1951–1955 as of November 16, 1951"), in *Atomnyi Proekt SSSR: Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 2 *Atomnaya Bomba. 1945–1954* (Atomic Bomb. 1945–1954) Book 7 (Gen. Ed. L D Ryabev, Exec. Comp. G A Goncharov) (Sarov: RFYaTs–VNIIEF, Moscow: Fizmatlit, 2007) p. 342; Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/atomny-proekt-sssr_t2_kn7_2007/p342/
55. Kagan Yu M "Akademik I.K. Kikoin. 100 let so dnya rozhdeniya" ("Academician I K Kikoin. 100 years since his birth"), in *I.K. Kikoin — Fizika i Sud'ba* (I K Kikoin — Physics and Destiny) (Ser. Monuments of Russian Science. XX Century, Gen. Ed. S S Yakimov) (Moscow: Nauka, 2008) p. 133; Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/kikoin-fizika-i-sudba_2008/p7/
56. "No. 266. Iz postanovleniya SM SSSR No. 1679-658ss/op 'O merakh po podgotovke k pusku i ekspluatatsii Gosudarstvennogo mashinostroitel'nogo zavoda Pervogo glavnogo upravleniya pri Sovete Ministrov SSSR'. 22 maya 1948 g." ("No. 266. From the resolution of the USSR Council of Ministers No. 1679-658ss/op 'On measures to prepare for the launch and operation of the State Machine-Building Plant of the First Main Directorate under the Council of Ministers of the USSR" as of May 22, 1948"), in *Atomnyi Proekt SSSR: Dokumenty i Materialy* (Soviet Atomic Project:

Documents and Materials) Vol. 2 *Atomnaya Bomba. 1945–1954* (Atomic Bomb. 1945–1954) Book 3 (Gen. Ed. L D Ryabev, Exec. Comp. G A Goncharov) (Sarov: RFYaTs–VNIIEF, 2002) p. 472; Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/atomny-proekt-sssr_t2_kn3_2002/p472/

57. Bazhenov V A et al. "Osvoenie gazotsentrifuzhnogo metoda razdeleniya izotopov na UEKhK" ("Development of the gas centrifuge method for separating uranium isotopes at Ural Electrochemical Combine"), in *Razrabotka i Sozdanie Gazotsentrifuzhnogo Metoda Razdeleniya Izotopov v SSSR* (*Rossii*) (Development and Creation of the Gas Centrifuge Method for Separating Isotopes in the USSR (Russia)) (St. Petersburg: LNPP "Oblik", 2002) p. 115; Electronic version on the website "History of Rosatom. Electronic library:" https://elib.biblioatom.ru/text/razrabotka-gazotsentrifuzhnogo-razdeleniya-izotopov_2002/p115/
58. Simonenko D L "O nekotorykh epizodakh sovmestnoi raboty s I.K. Kikoinym" ("On some episodes of joint work with I K Kikoin"), in *I.K. Kikoin — Fizika i Sud'ba* (I K Kikoin — Physics and Destiny) (Ser. Monuments of Russian Science. XX Century, Exec. Ed. S S Yakimov) (Moscow: Nauka, 2008) p. 659; Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/kikoin-fizika-i-sudba_2008/p659/
59. Tsukerman V A, Azarkh Z M *Lyudi i Vzryvy* (People and Explosions) (Arzamas-16: RFYaTs-VNIIEF, 1994); Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/tsukerman-azarh_lyudi-i-vzryvy_1994/p0_o/
60. Drovenikov I S, Romanov S V "Uran-45" ("Uranium-45") *Priroda* (6) 74 (2004); Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/drovenikov_uran-45_2004/p74/
61. Artemov E T, Bedel' A E *Ukroshchenie Urana*: *Stranitsy Istorii Ural'skogo Elektrokhimicheskogo Kombinata* (Taming Uranium: Pages of the History of the Ural Electrochemical Combine) (Novoural'sk: SV-96, 1999); Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/artemov_ukroschenie-urana_1999/p0/
62. Mazur V A "'Papa Karlo.' K stoletiyu so dnya rozhdeniya chlena-korrespondenta AN SSSR Sergeya Vasil'evicha Karpacheva, rektora Ural'skogo universiteta" ("'Papa Carlo.' On the centenary of the birth of corresponding member of the USSR Academy of sciences Sergei Vasil'evich Karpachev, rector of the Ural University in 1956–1963") *Izv. Ural. Gos. Univ.* (40) 234 (2006); Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/mazur_papa-karlo_2006/p234/
63. History of Rosatom. Electronic Library. Personalia: Karpachev Sergei Vasilievich, https://www.biblioatom.ru/persons/karpachev_sergey_vasilevich/
64. "No. 137. Postanovlenie SM SSSR No. 4964-2148ss/op 'O nagrazhdenii i premirovanii za vydayushchiesya nauchnye raboty v oblasti ispol'zovaniya atomnoi energii, za sozdanie novykh vidov izdelii RDS, dostizheniya v oblasti proizvodstva plutoniya i urana-235 i razvitiya syr'evoi bazy dlya atomnoi promyshlennosti'. 6 dekabrya 1951 g." ("No. 137. Resolution of the USSR Council of Ministers No. 4964-2148ss/op 'On awarding and rewarding outstanding scientific work in the field of atomic energy use, for the creation of new types of RDS products, achievements in the field of plutonium and uranium-235 production, and the development of a raw material base for the atomic industry' as of December 6, 1951"), in *Atomnyi Proekt SSSR*: *Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) Vol. 2 *Atomnaya Bomba. 1945–1954* (Atomic Bomb. 1945–1954) Book 7 (Gen. Ed. L D Ryabev, Exec. Comp. G A Goncharov) (Sarov: RFYaTs–VNIIEF, Moscow: Fizmatlit, 2007) p. 351; Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/atomny-proekt-sssr_t2_kn7_2007/p351/
65. Emel'yanenkov A F *Solo na Tsentrifuge* (Solo on a Centrifuge) (Moscow: ANO "Informatsionnyi Tsentr Atomnoi Otrasli", 2013); Electronic version on the website "History of Rosatom. Electronic library:" https://elib.biblioatom.ru/text/emelyanenkov_solo-na-tsentrifuge_2013/p0/
66. Uranium Enrichment, updated 11 October 2022. World Nuclear Association, https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx
67. Simonenko O D "Eksperimental'nye issledovaniya dlya sozdaniya promyshlennykh metodov razdeleniya izotopov urana v SSSR v 1943–1950 gg." ("Experimental studies for the development of industrial methods for separating uranium isotopes in the USSR in 1943–1950"), in *Nauka i Obshchestvo*: *Istoriya Sovetskogo Atomnogo Proekta* (*40-e–50-e gody*). *Trudy Mezhdunarodnogo Simpoziuma ISAP-96, Dubna, 14–18 Maya 1996* (Science and Society: History of the Soviet Atomic Project (1940s–1950s). Proc. of the Intern. Symp. ISAP-96, Dubna, May 14–18, 1996) Vol. 2 (Exec. Ed. Yu V Gaponov) (Moscow: IzdAT, 1999) p. 438; Electronic version on the website "History of Rosatom. Electronic library:" https://elib.biblioatom.ru/text/istoriya-sovetskogo-atomnogo-proekta_t2_1999/p438/
68. Gorelik G E "Vitalii Ginzburg: nauka i nrav nobelevskogo laureata. Po stranitsam Litgazety" ("Vitaly Ginzburg: science and character of the Nobel Laureate. On the pages of the Literary Newspaper"), in Ginzburg V *Pis'ma k Lyubimoi* (Letters to His Beloved) (Moscow: Vremya, 2016) p. 353 (afterword to the book); https://ggorelik.wordpress.com/%D1%81%D0%BF%D0%B8%D1%81%D0%BE%D0%BA-%D0%BF%D1%83%D0%B1%D0%BB%D0%B8%D0%BA%D0%B0%D1%86%D0%B8%D0%B9/%D0%B2%D0%B8%D1%82%D0%B0%D0%BB%D0%B8%D0%B9-%D0%B3%D0%B8%D0%BD%D0%B7%D0%B1%D1%83%D1%80%D0%B3-%D0%BF%D0%B8%D1%81%D1%8C%D0%BC%D0%B0-%D0%BA-%D0%BB%D1%8E%D0%B1%D0%B8%D0%BC%D0%BE%D0%B9-%D0%BC/#_%D0%A2%D0%BE%D1%81440138931
69. Vasil'ev A P "Sistema dal'nego obnaruzheniya yadernykh vzryvov i sovetskii atomnyi proekt" ("The system of early warning of nuclear explosions and the Soviet Atomic Project"), in *Istoriya Sovetskogo Atomnogo Proekta*: *Dokumenty, Vospominaniya, Issledovaniya* (History of the Soviet Atomic Project: Documents, Memoirs, Research) Issue 2 (Exec. Ed. and Comp. V P Vizgin) (St. Petersburg: RKhGI, 2002) p. 237; Electronic version on the website "History of Rosatom. Electronic library:" https://elib.biblioatom.ru/text/istoriya-sovetskogo-atomnogo-proekta_v2_2002/p237/
70. Prekul T S "Shtrikhi k portretu Sergeya Konstantinovicha Sidorova" ("Strokes to the portrait of Sergei Konstantinovich Sidorov"), in *Fizika Metallov na Urale. Istoriya Instituta Fiziki Metallov v Litsakh* (Physics of Metals in the Urals. History of the Institute of Metal Physics in Persons) (Ekaterinburg: RIO UrO RAN, 2012) p. 259; Electronic version on the website "History of Rosatom. Electronic library:" https://elib.biblioatom.ru/text/fizika-metallov-na-urale_2012/p259/
71. Pushin V G, Buinova L N "Vekhi puti: biografiya Nikolaya Nikolaevicha Buinova" ("Milestones: biography of Nikolai Nikolaevich Buinov"), in *Fizika Metallov na Urale. Istoriya Instituta Fiziki Metallov v Litsakh* (Physics of Metals in the Urals. History of the Institute of Metal Physics in Persons) (Ekaterinburg: RIO UrO RAN, 2012) p. 329; Electronic version on the website "History of Rosatom. Electronic library:" https://elib.biblioatom.ru/text/fizika-metallov-na-urale_2012/p329/
72. History of Rosatom. Electronic Library. Personalia: Tarasov Diodor Mikhailovich, https://www.biblioatom.ru/persons/tarasov_diodor_mikhailovich/
73. Tarasov M D *Istoriya Sem'i iz Zakrytogo Goroda* (History of a Family from a Closed City) 2nd ed., rev. and enlarg. (Sarov: FGUP RFYaTs-VNIIEF, 2020); Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/tarasov_istoriya-semyi_2020/p0/
74. Litvinov B V *Grani Proshedshego* (*Trptikh*) (Facets of the Past (Triptych)) (Moscow: IzdAT, 2006); Electronic version on the website "History of Rosatom. Electronic Library:" https://elib.biblioatom.ru/text/litvinov_grani-proshedshego_2006/p0_o/
75. "K 120-letiyu so dnya rozhdeniya Antona Panteleimonovicha Komara" ("On the 120th birthday of Anton Panteleimonovich Komar"). Section "Mounts with the Institute's Personnel." Website of the High Energy Physics Department of the National

Research Center ''Kurchatov Institute'' — PNPI, https://hepd.pnpi.spb.ru/hepd/Muzej_PNPI/stendy_personalij_instituta/stend_komar.pdf
76. *Komar Anton Panteleimonovich* (Ural State University in Biographies, Comp. V A Mazur) (Ekaterinburg: Izd. Ural. Gos. Univ., 2010); https://biography.ideafix.co/index55e9.html?base=mag&id=a_0130
77. Pushin V G ''Stanovlenie i razvitie issledovanii strukturnykh i fazovykh prevrashchenii v Institute'' (''Formation and development of research into structural and phase transformations at the Institute''), in *Fizika Metallov na Urale. Istoriya Instituta Fiziki Metallov v Litsakh* (Physics of Metals in the Urals. History of the Institute of Metal Physics in Persons) (Ekaterinburg: RIO UrO RAN, 2012) p. 389; Electronic version on the website ''History of Rosatom. Electronic library:'' https://elib.biblioatom.ru/text/fizika-metallov-na-urale_2012/p389/
78. Nasryeva M M ''Fritz Fritzevich Lange'', in *Fizika Metallov na Urale. Istoriya Instituta Fiziki Metallov v Litsakh 2.0* (Physics of Metals in the Urals. History of the Institute of Metal Physics in Persons 2.0) (Comp. I Yu Arapova et al.) (Ekaterinburg: Inst. Fiziki Metallov, 2023) p. 205
79. Gudina S V ''Daniil Lukich Simonenko,'' in *Fizika Metallov na Urale. Istoriya Instituta Fiziki Metallov v Litsakh 2.0* (Physics of Metals in the Urals. History of the Institute of Metal Physics in Persons 2.0) (Comp. I Yu Arapova et al.) (Ekaterinburg: Inst. Fiziki Metallov, 2023) p. 294
80. Memoirs of Volkov Vladimir Vladimirovich, a graduate of the UPI Physics and Technology Institute. Website FizikoTekhnik, https://new.fizikotekhnik.ru/FizikoTekhnik_Narod/FizikoTekhnik_MemVvv.htm
81. Lundin A B '''Ya vsyu zhizn' zanimalsya tem, chto menya interesovalo' (o Borise Nikolaeviche Lundine)'' (''All my life I have been engaged in things that were interesting to me' (about Boris Nikolaevich Lundin)''), in *Aktual'nye Problemy Khimii i Tekhnologii Organicheskikh Veshchestv. Istoriya, Problemy Organicheskogo Sinteza, Perspektivy* (Actual Problems of Chemistry and Technology of Organic Substances. History, Problems of Organic Synthesis, Prospects) (Exec. Eds V I Saloutin, O V Fedorova) (Ekaterinburg: UrO RAN, 2002) p. 39
82. Aleksandrov A P, Belyaev S T, Velikhov E P, Kagan Yu M, Kadomtsev B B, Legasov V A ''Isaak Konstantinovich Kikoin (Obituary)'' *Sov. Phys. Usp.* **29** 585 (1986); ''Pamyati Isaaka Konstantinovicha Kikoina'' *Usp. Fiz. Nauk* **149** 347 (1986)
83. Il'kaev R I, Ryabev L D ''The Academy of Sciences and implementation of the Atomic Project in the USSR (on the 75th anniversary of the Atomic industry'') *Phys. Usp.* **65** 488 (2022); ''Akademiya nauk i realizatsiya Atomnogo proekta v SSSR (k 75-letiyu Atomnoi otrasli'') *Usp. Fiz. Nauk* **192** 528 (2022)
84. Genkin Ya E, Kaipov D K, Kel'man V M, Kurdyumov G V, Usanovich M I, Chanyev S M ''Moisei Izrailevich Korsunskii (obituary)'' *Sov. Phys. Usp.* **20** 557 (1977); ''Pamyati Moiseya Izrailevicha Korsunskogo'' *Usp. Fiz. Nauk* **122** 345 (1977)
85. Genkin Ya E, Kaipov D K, Kel'man V M, Chanyshev S M ''Moisei Izrailevich Korsunskii (on his seventieth birthday'') *Sov. Phys. Usp.* **16** 581 (1974); ''Moisei Izrailevich Korsunskii (K semidesyatiletiyu so dnya rozhdeniya'') *Usp. Fiz. Nauk* **110** 471 (1973)
86. Genkin Ya E ''Moisei Izrailevich Korsunskii (On the occasion of his sixtieth birthday'') *Sov. Phys. Usp.* **6** 947 (1964); ''Moisei Izrailevich Korsunskii (K shestidesyatiletiyu so dnya rozhdeniya'') *Usp. Fiz. Nauk* **81** 779 (1963)
87. *Atomnyi Proekt SSSR*: *Dokumenty i Materialy* (Soviet Atomic Project: Documents and Materials) (Gen. Ed. L D Ryabev) Vol. 2 *Atomnaya Bomba. 1945–1954* (Atomic Bomb. 1945–1954) Book 1 (Sarov: RFYaTs–VNIIEF, 1999) p. 664; Electronic version on the website ''History of Rosatom. Electronic Library:'' https://elib.biblioatom.ru/text/atomny-proekt-sssr_t2_kn1_1999/p664/