appeared quite inconclusive [3, p. 187]. However, once the American atomic bomb had been exploded in 1945, all these doubts were blown away and the Inventions Department, recalling our applications, decided to issue the certificates.

It must be emphasized that our main purpose was not to receive inventor's certificates which, to be honest, were of no great importance at the time, but to put forward forceful arguments for starting the work which appeared to be of critical importance for the country. This is why we decided to address the USSR People's Commissar of Defense marshal S K Timoshenko at the beginning of 1941, and why V A Maslov sent him a letter arguing the need to organize work on using atomic energy for military purposes [3, pp. 224, 225]; among other things the letter said that "*...it appears extremely important to create as soon as possible, in one of the special-purpose research institutes, a laboratory specializing in uranium research, as this would make it possible for us to conduct research work in permanent contact with the most skilled technicians, chemists, physicists and military experts of our country*". Alas, no governmental decisions were made concerning this problem. Responding to my remarks, G A Goncharov and L D Ryabev explain in their subsequent text that the principle suggested by V A Maslov and myself for triggering a nuclear explosion, which consisted in placing uranium masses in partitioned chambers separated by neutron-impermeable walls which would be removed by an ordinary chemical explosion, could not work "*...because no materials exist that could serve to build sufficiently compact separating walls completely impervious to neutrons...*". Indeed, such materials do not exist. However, there is no need to have these walls completely impervious to neutrons, and we do recognize that the application used an imprecise formulation. The answer to the question of whether it was possible to ensure sufficient absorption of neutrons in the separating walls depends on the value of the volume occupied by the partition design. At that time the volume of interest could not be given because it depends on the critical mass which had not yet been established. Therefore, any judgement on the correctness or incorrectness of the principle formulated in our applications could only be made after the relevant experiments were completed.

The above arguments make it possible to conclude that if our proposals were accepted in due time, work on elucidation of the feasibility of using uranium energy for military purposes could be started in the USSR independently of the corresponding research work abroad, even before the Great Patriotic War of 1941 – 1945 — that is, two years before the State Defense Committee ordered the organization of the uranium research work.

V S Shpinel'

References

1. Goncharov G A, Ryabev L D "O sozdanii pervoĭ otechestvennoĭ atomnoĭ bomby" ("The development of the first Soviet atomic bomb") *Usp. Fiz. Nauk* **171** 79 (2001) [*Phys. Usp.* **44** 71 (2001)]
2. Zel'dovich Ya B, Khariton Yu B "Kinetika raspada urana" ("Kinetics of uranium decay") *Zh. Eksp. Teor. Fiz.* **10** (5) 477 (1940)
3. *Atomnyĭ Proekt SSSR: Dokumenty i Materialy* (The USSR Atomic Project: Documents and Materials) Vol. 1 *1938 – 1945* Pt. 1 (Editor-in-Chief L D Ryabev; Exec. comp. L I Kudinova) (Moscow: Nauka – Fizmatlit, 1998)

DOI: 10.1070/PU2002v045n02ABEH001067

About V S Shpinel's remarks on the review "The development of the first Soviet atomic bomb"

The authors of the review "The development of the first Soviet atomic bomb" [1] made a conscious decision to restrict the subject-matter of the paper to the topic formulated in the abstract: "*Based on documentary materials covering the period from 1939 to 1949, this paper traces the origin and evolution of the physical ideas behind the first Soviet atomic bomb and discusses the most important events associated with the project*". The review article reached a size very near the limit allowed for publications in the *Physics – Uspekhi*, and therefore the history of the work on manufacturing the active fissile materials, and especially the work on separation of uranium-235 which *was not* used in the design of the first Soviet atomic bomb, could not be described in detail and to a large extent was left outside of the aspects discussed in the review.

Therefore, commenting on the invention application which was directly relevant to the topic of paper [1], namely, that of V A Maslov and V S Shpinel' "The use of uranium as an explosive and toxic substance" of 17 October 1940 [2, pp. 193 – 196] which was submitted to the Inventions Bureau of the USSR People's Commissariat of Defense, the authors of Ref. [1] failed to mention the invention application by F F Lange, V A Maslov and V S Shpinel' "A method of preparing a mixture enriched in uranium with mass number 235. Multichamber centrifuge" [2, pp. 196 – 198], also accepted at the end of 1940 by the Inventions Bureau as a follow-up to the former application.

Nevertheless, paper [1] discussed the problem of separation of uranium isotopes, whose solution, in the opinion of a number of Soviet scientists before the Great Patriotic War, was inseparable from the very feasibility of implementing the nuclear chain reaction. The paper quoted part of a record made in V I Vernadsky's diary on June 1, 1941: "*We now face the problem of uranium as a source of energy — real, technical energy, and the problem may reform the entire technical capacity of mankind... Still, we have ongoing arguments: physicists focus on the nuclear theory, not on the particular goal set before physical chemists and geochemists, i.e. extracting the 235-isotope of uranium. Here we have to follow the theory, testing it at once by experience...*". Quoting this citation, the authors of article [1] expressed their agreement with Vernadsky's opinion on the importance of solving the problem of the separation of uranium isotopes — this was a straightforward problem standing in the path of achieving the release of atomic energy.

Even though the authors of Ref. [1], not aiming to outline the history of work on the separation of uranium isotopes,

G A Goncharov Russian Federal Nuclear Centre 'All-Russia Research Institute of Experimental Physics',
prosp. Mira 37, 607190 Sarov, Nizhniĭ Novgorod Region, Russian Federation
Tel. (7-831) 30 457 78. Fax (7-831) 30 427 29
E-mail: gagonch@vniief.ru
L D Ryabev Russian Federation Ministry for Atomic Energy,
B. Ordynka 24/26, 101000 Moscow, Russian Federation
Tel. (7-095) 239 21 90. Fax (7-095) 953 46 79

Received 28 November 2001
Uspekhi Fizicheskikh Nauk **172** (2) 236 – 238 (2002)
Translated by V I Kisin; edited by A Radzig

chose not to mention the inventor's application "A method of preparing a mixture enriched in uranium with the mass number 235. Multichamber centrifuge", they never doubted and do not doubt now that the creative initiative of F F Lange, V A Maslov and V S Shpinel' deserved the highest degree of praise. They stood at the beginning of the search for the implementation of the centrifugal isotope separation, whose future proved to be an extremely promising and efficient way of achieving separation of isotopes.

As for the factual component of V S Shpinel's remarks, the authors of Ref. [1] consider it necessary to point to the following aspects.

V S Shpinel' writes that at the moment when he and V A Maslov submitted their invention application "The use of uranium as an explosive and toxic substance" (October 1940) [2, pp. 193–196] "*...most Soviet physicists were very sceptical regarding the feasibility of solving this problem* (of separation of uranium isotopes in the required large amounts — Auths.)". "*Why were the designs* (of atomic bombs — Auths.) *devised and even submitted as invention applications if they are practically unusable*? (since "*the problem of nuclear explosive was considered infeasible*" — Auths.). *However, our applications were submitted and scrutinized, in today's terms, as a package. They greatly changed the situation and opened up ways for experimentally testing the feasibility of creating atomic bombs of various designs. This is the gist of the matter that we raise here*".

Nevertheless, archive documents published in Ref. [2] testify that the principal possibility of enriching uranium in the uranium-235 isotope was not an object of doubt in the USSR even *before* F F Lange, V A Maslov and V S Shpinel' submitted their invention application "A method of preparing a mixture enriched in uranium with the mass number 235. Multichamber centrifuge". When I V Kurchatov's report "On the uranium problem" was discussed at the session of the Division of Physico-Mathematical Sciences of the USSR Academy of Sciences on February 26, 1940, Ya I Frenkel' especially pointed out the possible promise of the diffusion method of separating uranium-235 in large amounts [2, pp. 101, 102]. Other methods of uranium separation were also known, and in 1940 the USSR Academy of Sciences was formulating decisions on organizing work on some of these methods. On 13 September 1940, i.e. before the submission of the application of F F Lange, V A Maslov and V S Shpinel', the Presidium of the USSR Academy of Sciences passed a resolution "On the main tasks of the USSR Academy of Sciences in 1941" where, in the section "Uranium problem", we find the following passage: "*Research programs in the physics and chemistry institutes of the Academy of Sciences of the USSR in 1941 must include large-scale research into clarifying the possibility and conditions of uranium decay and, in particular, include work on uranium isotope separation in order to investigate ways and means of utilizing the intraatomic energy which is released in decays of uranium nuclei*" [2, pp. 143, 144]. On 28 September 1940, the Uranium Commission of the Presidium of the USSR Academy of Sciences approved the plan of research and development in the institutes of the USSR AS and other organisations for 1941; the plan envisaged the development of separation techniques for uranium isotopes, including the development of the thermal-diffusion technique [2, pp. 165, 166, 188–192].

In fact, the problem of generating large amounts of uranium highly enriched in uranium-235 appeared to be extremely complicated. In the explanatory note of the Uranium Commission, appended to the above-mentioned research program, V G Khlopin and L V Komlev wrote: "*Calculations show, however, that a chain reaction is very unlikely in a mixture of ordinary uranium with water, because most of the neutrons are uselessly absorbed by the uranium-238 and hydrogen atoms* (heterogeneous systems were not discussed at the time — Auths.)... *The development of a chain reaction seems to be more feasible in a mixture of natural uranium with heavy hydrogen or heavy water, since in this case the undesirable neutron capture by hydrogen is eliminated... If a chain reaction cannot progress in a mixture of natural uranium and heavy hydrogen or heavy water, then we have to follow the very difficult path of obtaining uranium enriched in the U-235 isotope. To implement this approach, it is necessary to conduct extensive research and development of isotope separation techniques, having used* (verbatim as in the original document — Editor) *both known and novel ideas and proposals. If uranium sufficiently enriched in isotope-235 was ultimately produced, the development of a chain reaction would appear to be very probable; however, the need to generate very large amounts of the uranium-235 isotope, on the order of many kilograms, calls for very extensive research work, because until now it has only been possible to obtain only a few micrograms of uranium-235*." [2, pp. 186, 187].

In view of this, the proposals of F F Lange, V A Maslov and V S Shpinel' in their invention application "A method of preparing a mixture enriched in uranium with the mass number 235. Multichamber centrifuge" and the proposals of F F Lange and V A Maslov in their inventor's application "Thermal-circulation centrifuge" [2, pp. 213–216] which they submitted at the beginning of 1941, were undoubtedly very important because they objectively pointed to a new possibility of an effective solution to the problem of large-scale production of uranium enriched in uranium-235. However, in 1941 these proposals were not perceived as a ready and efficient solution to the problem of separation of uranium isotopes, even though their originality and the promise in the inherent ideas were unequivocally commended. The formulation in the findings of the Chemical Research Institute of the USSR People's Commissariat of Defense was: "*The first of these proposals — the multichamber centrifuge — appears to be a principally correct and feasible idea. However, it is unlikely that centrifugation, even improved by circulation, could prove to be a better option than the generally accepted technique of separation by thermal diffusion... This proposal shows originality but does not seem to be of any military promise*" [2, pp. 220, 221]. The inference drawn in the Radium Institute of the USSR Academy of Sciences on April 17, 1941, signed by V G Khlopin, stated: "*As for the proposals... for a multichamber and a thermal-circulation centrifuges, these proposals were discussed in the Uranium Commission of the USSR AS and were classified as deserving attention. It was concluded that experimental work on them is desirable in order to build pilot models of such centrifuges and to test on them certain assumptions and design features proposed by the authors. If these were verified, it would be a significant step forward in the separation of uranium isotopes and would greatly advance the work on the uranium problem. However, the Uranium Commission is of the opinion that neither of these two centrifuges promises a practicable unit that would provide separation of uranium isotopes in the amounts that are necessary for starting work on the practical utilization of these isotopes*" [2, pp. 228, 229].

Nevertheless, when the State Defense Committee made a decision on September 28, 1942 on resuming the work on the uses of atomic energy, interrupted by the outbreak of the war, the Order No. 2352ts "On Organizing Uranium Research" treated the centrifugation technique of uranium isotope separation as one of the fundamental methods of separating uranium-235. The Order of the State Defense Committee directed:

"*1. The Presidium of the USSR Academy of Sciences will*:

a) *organize a special Atomic Nucleus Laboratory at the USSR Academy of Sciences*;

b) *design and build at the Radiology Institute by January 1, 1943 a facility for thermal-diffusion separation of uranium-235*;

c) *using the centrifugation and thermal-diffusion techniques, produce at the Radiology Institute and the Physicotechnical Institute, by March 1, 1943, uranium-235 in the amounts required for the physical research, and by April 1, 1943 carry out research into the feasibility of the fission reaction of U-235 nuclei at the Atomic Nucleus Laboratory*.

2. The Academy of Sciences of the Ukrainian SSR (*Academician Bogomolets*) *will organize the design and development of a laboratory facility (supervised by Professor Lange*) *for the separation of uranium-235 by centrifugation, and by October 20, 1942 will transfer the technical project documentation to the* [*city of*] *Kazan' "Sickle and Hammer" heavy engineering works of the People's Commissariat of the Heavy Engineering Industry*.

3. The People's Commissariat of the Heavy Engineering Industry (*Cde. Kazakov*) *will build the laboratory centrifuge unit designed by Professor Lange in the Academy of Sciences of the Ukrainian SSR*; *the work will be completed by January 1, 1943 for the Academy of Sciences of the USSR at the Kazan' "Sickle and Hammer" factory of lifting and transportation machine building* [2, pp. 269 – 271].

However, the diffusion method of uranium isotope separation was later favored over the centrifugation technique. After the atomic explosions of American bombs over the Japanese towns of Hiroshima and Nagasaki on the 6 and 9 August 1945, the Soviet atomic project was assigned the top state priority in order to break, as soon as possible, the American atomic weapons monopoly. As a result, the laboratory research stage started to evolve to building large-scale atomic plants. Correspondingly, the USSR Council of People's Commissars passed resolution No. 3150-952ts, which ordered the immediate start of construction of factories Nos 813 and 817. The event occurred on December 21, 1945 [3, pp. 83 – 85]. Factory No. 813 (currently the Ural Electrochemical Group of Enterprises) was built to separate uranium-235 by the diffusion technique, and factory No. 817 [currently the "Mayak (Beacon)" Group of Enterprises] was the plutonium production plant. A number of other plants to produce plutonium and uranium-235 were later built, including new factories to separate uranium-235 by diffusion. Other methods of uranium isotope separation were also inculcated, including electromagnetic separation. In the mid 1950s, the centrifuge separation of uranium isotopes was launched in the USSR; the efficiency of this technique was much higher than that of the diffusion method and all other known techniques. The first industrial section equipped with first-generation centrifuges started operation in 1961. The new centrifuges differed essentially from the projects of prewar and war periods, and were based on new technologies that were constantly modernized. In 1970, the industrial use of fifth-generation centrifuges began. At the present moment, seventh-generation centrifuges are functioning successfully in Russia [4, pp. 392 – 397].

When discussing the October 17, 1940 inventor's application of V A Maslov and V S Shpinel' "The use of uranium as an explosive and toxic substance", the authors of Ref. [1] remarked that this application is of interest as the first in the USSR *pretending* to invent the design of the atomic bomb. Choosing the word "pretension", the authors of Ref. [1] meant nothing negative. The search undertaken by V A Maslov and V S Shpinel' for a way to overcome the difficulties in implementing an explosive nuclear reaction in uranium that Ya B Zel'dovich and Yu B Khariton had pointed out (the difficulties as they conceived at the moment) was definitely extraordinary and deserved maximum attention — at the time when even the principal possibility of creating conditions for initiating this reaction was very much in doubt. The positive assessment of their initiative cannot be affected even by the fact that the technical solution proposed in their application (briefly: subcritical masses of uranium-235 would be placed in partitioned chambers separated by neutron-impervious walls that were to be removed when acted upon by chemical explosive) was impracticable because no materials existed that could serve to build sufficiently compact separating walls completely impervious to neutrons (and whose presence makes "*the penetration of neutrons from a chamber to adjacent ones completely impossible*") [2, pp. 193 – 196].

If the practicable materials were used, the effect of the separating walls in the space (gaps) between the uranium-235 elements on criticality would be relatively insignificant in the design proposed. In this case the absorption of neutrons in the partition materials reduces criticality, while the scattering and slowing down of neutrons, on the contrary, increases it. As a result, even a weak transition of the system through the critical state by removing the partitions becomes rather problematic. Whereas this design makes impossible the achievement of high supercriticality that is required for the system to operate as an atomic bomb.

G A Goncharov, L D Ryabev

References

1. Goncharov G A, Ryabev L D *Usp. Fiz. Nauk* **171** 79 (2001) [*Phys. Usp.* **44** 71 (2001)]
2. *Atomnyĭ Proekt SSSR*: *Dokumenty i Materialy* T. 1 *1938 – 1945* Chast' 1 (The USSR Atomic Project: Documents and Materials. Vol. 1. 1938 – 1945. Part 1) (Editor-in-Chief L D Ryabev; Exec. comp. L I Kudinova) (Moscow: Nauka, Fizmatlit, 1998)
3. *Atomnyĭ Proekt SSSR*: *Dokumenty i Materialy* T. 2 *Atomnaya Bomba 1945 – 1954* Kn. 2 (The USSR Atomic Project: Documents and Materials. Vol. 2. 1945 – 1954. Part 2) (Editor-in-Chief L D Ryabev; Exec. comp. G A Goncharov) (Moscow: Nauka, Fizmatlit; Sarov RFYaTs-VNIIEF, 2000)
4. *Yadernaya Industriya Rossii* (Nuclear Industry of Russia) (Editor-in-Chief A M Petros'yants) (Moscow: Energoatomizdat, 2000)