November 28, 1945
The Interrogation of Niels Bohr

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Summary:

At the end of October 1945 two NDVD employees of the “S” Department for atomic intelligence activities were sent to Denmark to establish contact and speak with Niels Bohr. They managed to meet Bohr at his institute twice, on 14 and 16 November 1945, and obtained answers to 22 questions on constructing a nuclear reactor and the atomic bomb.

Original Language:

Russian

Contents:

1. Question: By what practical method was uranium 235 obtained in large quantities, and which method now is considered to be the most promising (diffusion, magnetic, or some other)?

Answer: The theoretical foundations for obtaining uranium 235 are well known to scientists of all countries; they were developed even before the war and present no secret. The war did not introduce anything basically new into the theory of this problem. Yet, I have to point out that the issue of the uranium pile [kotiol; reactor--ed.] and the problem of plutonium resulting from this -- are issues which were solved during the war, but these issues are not new in principle either. Their solution was found as the result of practical implementation. The main thing is separation of the uranium 235 isotope from the natural mixture of isotopes. If there is a sufficient amount of uranium 235, realizing an atomic bomb does not present any theoretical difficulty. For separation of uranium 235, the well-known diffusion method is used, and also the mass-spectographic method. No new method is applied. The Americans succeeded by realizing in practice installations, basically well-known to physicists, in unimaginably big proportions. I must warn you that while in the USA I did not take part in the engineering development of the problem and that is why I am aware neither of the design features nor the size of these apparatuses, nor even of the measurements of any part of them. I did not take part in the construction of these apparatuses and, moreover, I have never seen a single installation. During my stay in the USA I did not visit a single plant. While I was there I took part in all the theoretical meetings and discussions on this problem which took place. I can assure you that the Americans use both diffusion and mass-spectrographic installations.

2. Question: How can the space charge of the ionic beam in a mass-spectrograph be compensated for?

Answer: If the gas from the vacuum chamber is pumped out completely, we will have to think about a way to compensate for the volume charge of the ionic beam. But if the gas from the chamber is not pumped out completely, it is not necessary to worry about compensating for the volume charge. Or, in fact, compensation for the volume charge of the ionic beam is accomplished by means of the incomplete pumping of gas from the vacuum chamber.

3. Question: Is it feasible to execute a uranium pile using a natural mixture of isotopes and ordinary ["light"--ed.] water as a moderator?

Answer: The question of using ordinary water as a moderator was raised, yet the idea was not realized in practice. The uranium pile with ordinary water is not used. I think that the use of ordinary water as a moderator is not expedient, because light hydrogen absorbs neutrons well, thus turning into heavy hydrogen. This idea is not popular in America. Originally the Americans intended to build piles with heavy water as a moderator, but production of heavy water requires huge expense. During the war the Americans discovered that graphite can serve as a good moderator. They developed this idea in practice and implemented it on a gigantic scale. The construction side, the arrangement and the measurements of this pile, is not known to me.

4. Question: What substance is used for cooling the uranium blocks themselves?

Answer: Normal water is used for cooling the uranium blocks. The problem of cooling the uranium piles is extremely complicated, since cooling the piles literally requires whole rivers. We note that the water used for cooling is brought almost to boiling.

5. Question: What is the temperature change of the multiplication factor, what is the numerical equivalent of the temperature coefficient of the multiplication factor? Or

what does the curve representing the relationship between the multiplication factor and temperature look like?

Answer: The mere fact that the uranium pile is working means that the dependence of the multiplication factor on temperature is not significant. Otherwise, as the result of the violent reaction, the pile would explode. I cannot provide the numerical significance of this dependence, but evidently it is of an insignificant size. However, this factor must not be ignored. It is necessary to maintain the pile in a certain state by regulating the amount of water coming into it. Normally uranium cores are kept in cold condition. It is necessary to keep in mind that if the pile's working regime is disrupted, the pile can be easily spoiled. We also note that the possibility of regulating the uranium pile is provided by the existence of a long period of time /about a second and more/ between the fission of the nucleus and the emission of slowed neutrons, which comprise 1% of the total number of emitted neutrons.

/Then BOHR on the basis of his work, done with [Princeton University physicist John A.] WHEELER, explained this thesis to Prof. TERLETSKY in detail./

6. Question: Are there other supplementary methods for regulating the uranium pile?

Answer: For this purpose, regulating substances which absorb neutrons are loaded into the pile.

7. Question: Which substance is used as the absorber?

Answer: It seems that the absorbent rods are made of cadmium.

8. Question: How many neutrons are emitted from every split atom of uranium 235, uranium 238, plutonium 239 and plutonium 240?

Answer: More than 2 neutrons.

9. Question: Can you not provide exact numbers?

Answer: No, I can't, but it is very important that more than two neutrons are emitted. That is a reliable basis to believe that a chain reaction will most undoubtedly occur. The precise value of these numbers does not matter. It is important that there are more than two.

10. Question: What is the number of spontaneous disintegrations [i.e., fissions--ed.] within a segment of time for all the mentioned substances /uranium 235, uranium 238, plutonium 239, plutonium 240/?

Answer: Few spontaneous disintegrations take place, and in calculations it is not necessary to take them into consideration. The period of spontaneous fission is approximately 7,000 years. I can't cite the precise numbers, but you yourself understand that with such a period of spontaneous disintegration, there is no reason to expect it to influence the process significantly.

11. Question: In order to obtain a large quantity of uranium 235, is either the diffusion method or mass-spectographic method used alone, or are these two methods also used in combination?

Answer: The Americans use both methods and, besides, they use the combination of

these two methods. I think that the combination of these two methods is most effective, because if we presume that we have 0.5% of uranium 235 and if, as a result of applying the diffusion method by passing it through a cascade, we increase the uranium content by 5 times, then by putting the uranium after that into the chamber of a spectograph, we can accelerate the process by 5 times. I do not know for certain, but I think that the Americans use the combination of these two methods very widely.

12. Question: How stable is the multi-stage machine?

Answer: The fact that diffusion cascades of very many stages already work in the USA shows that the process can and does take place. And it is not new. As you know, the German scientist [Gustav] HERTZ long before the war proved already that this process was possible, when he split helium, neon.

13. Question. How is high productivity achieved using the mass-spectrographic method; is it by constructing a large number of ordinary spectrographs, or by constructing a few powerful spectrographs?

Answer: Both. You cannot imagine what an enormous number of huge spectrographs the Americans built. I do not know their size and number, but I know that it is something incredible. From the photographs which I saw it is possible to conclude that these are gigantic buildings with thousands of apparatuses installed in them, and that many plants like this were built. In such a way the Americans built a large number of big spectographs.

14. Question: By what method is it possible to obtain high ion charges of uranium or its compounds?

Answer: By constructing a large and powerful mass-spectograph.

15. Question: Does the pile begin to slow as the result of slag formation in the course of the fission of the light isotope of uranium?

Answer: Pollution of the pile with slag as the result of the fission of a light isotope of uranium does occur. But as far as I know, Americans do not stop the process specially for purification of the pile. Cleansing of the piles takes place at the moment of exchange of the rods for removal of the obtained plutonium.

16. Question: How often is plutonium removed from the machine and how are the terms for the removal determined?

Answer: I do not know for sure. By unconfirmed hearsay, the removal of the rods takes place once a week.

17. Question: Does plutonium 240 split under the influence of slow neutrons? Has the possibility of plutonium 240 fission been proved experimentally?

Answer: It is known that the fission of all even isotopes, uranium 234, uranium 238 and plutonium 240, requires significantly more energy than uneven isotopes /let's recollect [Austrian physicist Wolfgang] Pauli's principle/, and that the energy released by plutonium 240 must be equal to the energy released by the fission of uranium 239. /At this point BOHR, illustrating his speech with graphs from his works, gave a detailed foundation for the fact that the question of using plutonium 240 is not very sensible./ So far nobody has proved by experiment that it is possible to split plutonium 240.

18. Question: Does a uranium pile using heavy water as a moderator exist, or are all working piles uranium-graphite?

Answer: All piles working in the USA have graphite moderators. You evidently know that production of heavy water demands an enormous amount of electric power. Before the war the production of heavy water was organized only in Norway. And we all bought heavy water there. We note that during the war the Germans applied much effort in order to carry out processes with heavy water, but they did not manage to collect the amount of heavy water sufficient to start a pile. The Americans found it possible to use graphite as a moderator and accomplished this idea with considerable success. Therefore, as far as I know, they gave up using piles with heavy water for industrial production. The Canadians chose another way, deciding to construct piles with heavy water, but these piles have not been activated for the same reason: they cannot accumulate for this purpose the necessary amount of heavy water. I consider it necessary to stress that I received this information during informal conversations with my colleagues.

19. Question: Of which substance were atomic bombs made?

Answer: I do not know of which substance the bombs dropped on Japan were made. I think no theoretician will answer this question to you. Only the military can give you an answer to this question. Personally I, as a scientist, can say that these bombs were evidently made of plutonium or uranium 235.

20. Question: Do you know any methods of protection from atomic bombs? Does a real possibility of defense from atomic bombs exist?

Answer: I am sure that there is no real method of protection from atomic bomb. Tell me, how you can stop the fission process which has already begun in the bomb which has been dropped from a plane? It is possible, of course, to intercept the plane, thus not allowing it to approach its destination--but this is a task of a doubtful character, because planes fly very high for this purpose and besides, with the creation of jet planes, you understand yourself, the combination of these two discoveries makes the task of fighting the atomic bomb insoluble. We need to consider the establishment of international control over all countries as the only means of defense against the atomic bomb. All mankind must understand that with the discovery of atomic energy the fates of all nations have become very closely intertwined. Only international cooperation, the exchange of scientific discoveries, and the internationalization of scientific achievements, can lead to the elimination of wars, which means the elimination of the very necessity to use the atomic bomb. This is the only correct method of defense. I have to point out that all scientists without exception, who worked on the atomic problem, including the Americans and the English, are indignant at the fact that great discoveries become the property of a group of politicians. All scientists believe that this greatest discovery must become the property of all nations and serve for the unprecedented progress of humankind. You obviously know that as a sign of protest the famous OPPENHEIMER retired and stopped his work on this problem. And PAULI in a conversation with journalists demonstratively declared that he is a nuclear physicist, but he does not have and does not want to have anything to do with the atomic bomb.

I am glad to note that today in the local newspaper there appeared a report that [British Prime Minister Clement] ATTLEE and [U.S. President Harry] TRUMAN began a consultation with the USSR on the establishment of international control over the use and production of atomic bombs. Yet, I have to point out I view such reports in local newspapers very skeptically. But the mere fact that ATTLEE, TRUMAN, and [Canadian Prime Minister Mackenzie] KING conduct these negotiations is very notable. Let us see where they will lead.[1] We have to keep in mind that atomic energy, having been discovered, cannot remain the property of one nation, because any country

which does not possess this secret can very quickly independently discover it. And what is next? Either reason will win, or a devastating war, resembling the end of mankind.

21. Question: Is the report which has appeared about the development of a super-bomb justified?

Answer: I believe that the destructive power of the already invented bomb is already great enough to wipe whole nations from the face of the earth. But I would welcome the discovery of a super-bomb, because then mankind would probably sooner understand the need to cooperate. In fact, I believe that there is insufficient basis for these reports. What does it mean, a super-bomb? This is either a bomb of a bigger weight then the one that has already been invented, or a bomb which is made of some new substance. Well, the first is possible, but unreasonable, because, I repeat, the destructive power of the bomb is already very great, and the second--I believe--is unreal.

22. Question: Is the phenomenon of overcompression of the compound under the influence of the explosion used in the course of the bomb explosion?

Answer: There is no need for this. The point is that during the explosion uranium particles move at a speed equal to the speed of the neutrons' movement. If this were not so the bomb would have given a clap and disintegrated as the body broke apart. Now precisely due to this equal speed the fissile process of the uranium continues even after the explosion.

[1] On 15 November 1945, at a summit in Washington, Truman, Attlee, and King issued a tripartite declaration recognizing the impossibility of defense against the atomic bomb or keeping a national monopoly over atomic weapons or science, and calling for the United Nations to create a commission to establish international exchange of scientific information. This policy led to the unsuccessful UN talks over the Baruch and Gromyko plans for international control.--ed.