

Niels Bohr and Nuclear Weapons

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Abstract

The chapter shows that, in the light of the Bohr–Wheeler paper of September 1939 which interpreted the fission process, Bohr believed that an atomic bomb was impossible. It relates how he was brought out of occupied Denmark by the British to join the Anglo–American wartime bomb project, how he immediately saw the political implications of the bomb, and advocated unsuccessfully that in the interests of postwar international control, Russia should be told about the bomb before it was used. The chapter also discusses Bohr’s postwar Letter to the United Nations. It assesses the value of both these arms control initiatives by Bohr.

It was one of the most fateful coincidences of history that the discovery of uranium fission by Hahn and Strassman and the theoretical explanation of the phenomenon by Meitner and Frisch were published at the beginning of the year of the outbreak of World War II. In April 1939 Joliot–Curie’s team in Paris was the first to announce experimental evidence that in fission spare neutrons were released; this opened the possibility of a nuclear chain reaction and an atomic bomb. The widespread and agitated discussion of this project diminished when, on September 1st, the day Germany invaded Poland, an article by Bohr and Wheeler was published in *Physical Review* [1], giving the classic interpretation of the fission process. This included the important deduction (already foreshadowed by Bohr in a letter of February 7, 1939 to the same journal [2]) that it was the rare uranium U 235 nuclei, not the uranium U 238 nuclei, that fissioned: a deduction consistent with the observation that fission was much more likely with moderated, slow neutrons than with fast ones. It seemed that these slow-neutron chain-reactions might produce power, but not the fantastically fast reaction necessary for a bomb.

This basic knowledge of fission was available to the whole world and in the subsequent two years, scientists in the belligerent European countries—Britain, France and Germany—and the non-belligerent United States worked on bomb possibilities. The most effective work was done in Britain by the famous Maud Committee. The strange name of this committee was derived from a telegram sent by Lise Meitner from Sweden in May 1940, just after Denmark was invaded by the Germans, to the physicist O.W.R. Richardson: “Met Niels and Margarethe recently. Both well but unhappy about events. Please inform Cockcroft and Maud Ray Kent.” Cockcroft believed the last words were an anagram for “radiumtaken” and

the words seemed a good code name. When Bohr arrived in England in 1943 he asked whether the message ever reached his old governess Maud Ray who lived in Kent.

The Maud Committee was composed of British and refugee scientists. A paper of April 1940 by Otto Frisch and Rudolf Peierls—both refugees at Birmingham University, England—had instigated the Committee by showing that a small lump of U 235 would give the fast reaction necessary for a bomb and by proposing an industrial method for separating the U 235. When France fell, two members of Joliot-Curie's team fled to Britain and a slow-neutron team developed round them. Two members of the team soon suggested that in a slow neutron reaction the element 94, foreshadowed by Macmillan and Abelson in the United States in May 1940, would be produced and that it would also be an efficient super-explosive with a small critical mass. Unknown to the British, Berkeley scientists in March 1941 demonstrated experimentally that this was so.

Several groups of American scientists were working on many aspects of "the uranium problem" but in a diffuse, leisurely way. It did not become urgent to them until in July 1941 they were shown the British Maud Report, which showed most coherently and cogently why and how an atomic bomb was possible. Their government set up, even before the attack on Pearl Harbour in December 1941 ended the United States' neutrality, what was soon to become the huge Manhattan Project.

The great fear was that Germany might make a bomb first, but, most mercifully, their project floundered in its science and its organisation.

After the invasion of Denmark in 1940, Bohr was preoccupied with the grave problems of his country and his Institute, including its refugees from Nazism; he faced them with dignity, courage and deep patriotism. Atomic bombs were not a main concern for him. He had explained in a lecture at the outbreak of the war [3] that an explosion could indeed be achieved with a sufficiently large amount of U 235 but he did not think that it would be technically possible to separate enough U 235. He did not at that time consider the possible slow-neutron route to a bomb. He was therefore deeply disturbed by a visit from the great German physicist Heisenberg in October 1941. Robert Jungk in his well-known book *Brighter than a Thousand Suns* calls this visit

"a little known peace feeler. By the expedient of a silent agreement between German and Allied atomic experts, the production of a morally objectionable weapon was to be prevented."

This suggestion of German moral scruples is supported in the book by a letter to Jungk from Heisenberg about this visit to Bohr. Aage Bohr, who was so close to his father in these nuclear events, has written that Heisenberg put no proposal to Niels for a physicists' agreement not to develop nuclear weapons, but that he left the strong impression that the Germans attributed great military importance to atomic energy.

Early in 1943 a message reached Niels Bohr in a micro-dot in a key handle from James Chadwick, the British physicist who had discovered the neutron and who was

the informal scientific leader of the British atomic project. Chadwick wrote that he had heard,

“you have considered coming to this country if the opportunity should offer. I need not tell you how delighted I myself should be to see you again ... There is no scientist in the world who would be more acceptable both to our university people and to the general public ... I have in mind a particular problem in which your assistance would be of the greatest help ...”

Bohr still felt that it was his duty to remain in Denmark, but he replied to Chadwick that he might leave if he felt he could be of real help. He said that he did not think this probable, adding:

“I have to the best of my judgment convinced myself that, in spite of all future prospects, any immediate use of the latest marvellous discoveries of atomic physics is impracticable.”

Two months later he reported to Chadwick rumours of German preparations for producing metallic uranium and heavy water in order to make atomic bombs. However, he was still sceptical about such bombs. The Bohr–Chadwick messages were buried in the garden at Carlsberg to be found after the war.

In September 1943 Bohr and his family, who were now in danger of arrest, fled to Sweden and the British Atomic Directorate arranged for Niels and Aage to go to England. Niels departed on October 6, 1943, in an unarmed bomber which flew at great height. The earphones did not fit his large head and, not hearing the order to turn on the oxygen, he became unconscious but recovered as the plane lost height. Aage arrived a week later.

On his arrival in England, Niels was immediately told everything about the British and American projects: it now seemed almost certain that the Americans would produce nuclear weapons within a year or two. Father and son were received most warmly by the scientists, by the administrators of the code-named Tube Alloys project and by the Minister in charge—Sir John Anderson, later Lord Waverley, who was Chancellor of the Exchequer and who was henceforth to be a very warm friend of the Bohr family. The Bohrs had arrived at an important moment for the British project. Their Maud Report had pushed the scattered, ill-organised American project off the ground, but the over-confident British had preferred an independent atomic project in co-operation with the Americans rather than the full integration between the projects which Roosevelt had suggested when they received the Maud Report. However, the American project soon far outstripped the British and neither needed nor wanted British help. The British, already highly mobilised and unable to build huge atomic plants, became desperate: they could not proceed on their own and were cut off from American knowledge. It was only after a great struggle that Churchill persuaded Roosevelt to sign the Quebec Agreement in August 1943 which enabled British scientists to participate in some parts of the American project, notably at Los Alamos where the bombs were to be fabricated.

Bohr, so welcome to the British for his own sake, was also, as a member of their team in America, a trump card for them in implementing the Quebec Agreement.

Bohr promised that he would not allow himself to be drawn into the American orbit, that he would assist the common effort and also do everything he could to make the association between America and Britain a real partnership. He and Aage arrived in the United States early in December 1943 under the cover names Nicholas and James Baker, or affectionately to colleagues Uncle Nick and Jim. They were not attached to any specific team but Bohr's main scientific contribution was to the work at Los Alamos, where he found many of his former students. There he stimulated and liberated scientific ideas which gave rise to theoretical and experimental activities which cleared up unanswered questions—for example on the velocity selector, bomb assembly and the design of the initiator. Old and new friendships flourished here.

Bohr was fascinated by the vast Manhattan Project, built as it was on theoretical foundations he had laid. However, he was infinitely—and immediately—more impressed with the implications of this weapon of unparalleled power for the future of the world. He had the reputation for being the most unworldly of scientists but the unworldliness was purely behavioural. His knowledge of philosophy, history and politics was profound and had been deepened by the experience of the refugees from Nazism at his Institute in the 1930s and by the German occupation. His exceptionally imaginative intuition marked not only his science but also his view of world politics. He immediately realised when he saw the Manhattan Project that it was only a beginning; at Los Alamos scientists already foresaw a hydrogen bomb.

Bohr was concerned privately with the question of how soon the weapon would be ready for use and what role it might play in the Second World War but he took no part in discussions about whether the bomb should be dropped on Japan. He looked rather to the years after the war and the terrifying prospect of an atomic arms race. After his very first visit to Los Alamos he wrote to London that future effective control would involve not only the most intricate technical and administrative problems, but also concessions over exchange of information and openness about industrial efforts and military preparations that were hardly conceivable in terms of prewar international relationships. Bohr felt that the invention of atomic bombs was so climacteric that it would facilitate a whole new approach to these relationships.

Before long his thoughts crystallised into a precise proposition. Despite the wartime alliance with Russia, after she entered the war in June 1941, Bohr believed that there would be tension between the West and Russia after the war and that confidence might be promoted by telling Russia about the bomb before it was used. Conversely, he believed that it would be disastrous if Russia should learn of it on her own. Knowing very well the competence of the Russian physicists, Bohr felt certain that the margin of time before the Russians made a bomb themselves would be very small. This conviction was strengthened when, in London, in April 1944, he received a letter from Peter Kapitza, written six months earlier when Bohr escaped to Sweden, inviting him to settle in Russia. This reinforced Bohr's belief that the Russians were aware of the American project. He sent back a warm, innocuous reply to Kapitza and showed the correspondence to the British authorities.

The political implications of the bomb had become Bohr's prime concern and he spent much of his time writing "political" memoranda and in haunting the offices

and anterooms of those who had political power or access to it. His discursive talk and his low, indistinct voice were not easy to follow but he made important converts among British Ministers and officials: Lord Halifax and Sir Ronald Campbell, respectively Ambassador and Minister at the British Embassy in Washington and, most significantly, Sir John Anderson and Lord Cherwell (the scientist who was Churchill's personal adviser) and Field Marshal Smuts (Prime Minister of South Africa). Halifax told Bohr, however, that because of America's preponderant share in the project, any initiative would have to come from President Roosevelt. It seemed fortunate therefore that Bohr was able to resume a prewar friendship with Mr Justice Frankfurter, a Supreme Court Judge, and a friend of Roosevelt, who already knew about the bomb. He communicated Bohr's ideas and hopes to the President, who said the whole thing "worried him to death" and that he was most eager to explore it with Churchill.

In March 1944 Sir John Anderson wrote to Churchill that the Americans would almost certainly get a bomb first but that Russia would most probably put forward a great effort once they had expelled the Germans. Moreover, the project would come within the capacity of other countries. There were two alternatives: a particularly vicious armaments race in which at best America and Britain would for a time enjoy a precarious and uneasy advantage, or a form of international control must be devised. If it was decided to work for international control there was much to be said for communicating to Russia in the near future the bare fact that the Americans expected by a given date to have this devastating weapon and for inviting them to collaborate in preparing a scheme for international control. If the Russians were told nothing they would learn sooner or later what was afoot and might then be less disposed to co-operate. There was little risk that Russia, if she chose to be unco-operative, would be much helped by such a communication. Cherwell added his plea:

"I must confess that I think plans and preparations for the postwar world and even the peace conference are utterly illusory, so long as this crucial factor is left out of account."

Churchill disagreed profoundly and constantly repeated his conviction that the project must be kept absolutely as secret as possible.

Pressed by Smuts, Cherwell and Sir Henry Dale, President of the Royal Society, Churchill saw Bohr on May 16, 1944. This was only two weeks before the Allied invasion of France, and, perhaps partly for that reason, the meeting was a tragic failure. His friends had feared that Bohr's "mild, philosophical vagueness of expression and his inarticulate whisper" might prevent a "desperately pre-occupied Prime Minister" from understanding him and so it proved. The main point was never reached. "We did not speak the same language," said Bohr afterwards. Later Churchill told Cherwell: "I did not like the man when you showed him to me, with his hair all over his head."

However, Churchill realised that he must discuss the long-term problem of the atomic bomb with the President when they next met in September 1944. Before then Roosevelt had received a memorandum by Bohr which outlined the scientific basis of the project, his own feelings on seeing the project after his escape from Denmark,

Kapitza's approach to him, his belief that the project offered an opportunity for a new spirit and new hope in international relations, his fears of a nuclear arms race between Russia and the West. On August 26, Roosevelt had an interview of 1½ hours with Bohr in complete privacy.

Bohr reiterated his belief that there was a great opportunity for better world relations provided it was seized now rather than later. He expanded on his reasons for urging an approach to Russia and on his arguments against those who said that the West would lose thereby. He said it must be assumed that the Russians knew great efforts were being made in the United States to make a bomb; that the Russians themselves were studying the matter and would be free to develop a full effort at the end of the German war; that the Russians would probably obtain the German secrets at the end of the war. If America and Britain said nothing before a bomb was used they would, urged Bohr, arouse Russian suspicions and create a greater risk of fateful competition in atomic weapons. They would lose the opportunity of using an approach to Russia in order to establish confidence. Bohr emphasised that it was not necessary to begin by giving the Russians detailed information about the bomb. The approach should be general and if the Russians responded in a co-operative spirit the way would be open for frank discussions. If not, the West would know where they stood. Bohr believed that an approach might be possible through preliminary and noncommittal contact between scientists.

The President was most friendly to Bohr and open and frank in his discussions of the political problems raised by the bomb. He said that an approach to Russia must be tried and that it would open a new era of human history. Stalin, he believed, was a sufficient realist to understand the implications of this scientific and technological revolution. Encouraged by his talk with Roosevelt, Bohr drafted a letter to Kapitza on the lines discussed and held himself ready to go to Russia. Bohr's high hopes were soon destroyed. In September 1944 when Churchill and Roosevelt met and discussed the atomic bomb, the results were very different from those foreshadowed during Bohr's interview with Roosevelt. They signed an agreement which not only said that no other country was to be told about the bomb but also included a paragraph saying that enquiries were to be made about Professor Bohr and steps taken to ensure that he leaked no information, particularly to the Russians.

This agreement, besides turning down Bohr's proposal for an approach to Russia, put his good faith and honour in question. Churchill wrote forcefully to Lord Cherwell:

“The President and I are much worried about Professor Bohr. How did he come into the business? He is a great advocate of publicity. He made an unauthorised disclosure to Chief Justice Frankfurter who startled the President by telling him he knew all the details. He said he is in close correspondence with a Russian professor, an old friend of his in Russia, to whom he has written about the matter and may be writing still. The Russian professor has urged him to go to Russia in order to discuss matters. What is all this about? It seems to me Bohr ought to be confined or at any rate made to see that he is very near the edge of mortal crimes.”

Bohr's ministerial friends rushed to defend him and to say that Churchill was talking nonsense. Cherwell sent a strong reply to Churchill telling him how Bohr

had come into the business, about the Bohr–Frankfurter talks, the story of the approach by Kapitzka and the reply that had been agreed by British Intelligence:

“I have always found Bohr most discreet and conscious of his obligations to England to which he owes a great deal and only the very strongest evidence would induce me to believe that he had done anything improper in this matter. I do not know whether you realise that the possibilities of this super weapon have been publicly discussed for at least six or seven years. The things that matter are which processes are proving successful, what the main stages are and what stage has been reached. Most of the rest is published every silly season in most newspapers.”

Cherwell repeated these views to Roosevelt in the presence of Vannevar Bush, the eminent American scientist, who agreed with them. Churchill accepted Cherwell’s opinion about Bohr and the matter was dropped. Bohr, when he heard of the misunderstanding, was distressed; he might have been deeply offended but his sense of humour was always stronger than his pride.

We do not know the reasons for Roosevelt’s *volte face*. As for Churchill, he believed passionately in the desirability and possibility of keeping atomic weapons secret. At home he kept the matter secret from most of the War Cabinet (including the Labour leader, Mr Attlee, who in July 1945 became Prime Minister) and from his Defence advisors, and he refused to impart any information to the French, to whom the British had atomic obligations. He wrote:

“You may be quite sure that any power that gets hold of the secret will try to make the article and that this touches the existence of human society. The matter is one out of all relation to anything else that exists in the world and I could not think of participating in any disclosure to third or fourth parties at the present time. I do not believe there is anyone in the world who can possibly have reached the position now occupied by us and the United States.”

Meanwhile, Bohr found himself exercising a restraining hand on Einstein, who in December 1944 sent him a *cri de coeur* about the prospect of a postwar arms race. The politicians, he said, did not appreciate the threat. In all the principal countries influential scientists had the ear of political leaders—Bohr himself, Compton, Cherwell, Kapitzka and Joffe. These men should come together to bring pressure to bear on their political leaders to strive for the internationalisation of military power. “Don’t say impossible,” wrote Einstein to Bohr, “but wait a few days until you have accustomed yourself to these strange thoughts.” Bohr went to see Einstein and explained to him that it would be quite illegitimate and might have the most deplorable consequences if anyone who knew about the bomb should take the initiative into his own hands. Bohr assured Einstein that the attention of responsible statesmen in England and America had been called to the implications of the bomb. Einstein thereupon agreed to abstain from action and to impress on his friends the undesirability of doing anything that might complicate the statesmen’s task.

Bohr, conscious that time was running out, became increasingly convinced that postponement of any discussion with Russia until a bomb was demonstrated might give the appearance of an attempt at coercion in which no great nation could be expected to acquiesce. He emphasised yet again that Russia would soon learn, at the least, about the German work. In April 1945, Lord Halifax and Frankfurter walked

through Rock Creek Park in Washington discussing how to get Bohr's proposals properly considered. As they ended their walk, they heard all the bells in Washington tolling. Roosevelt was dead.

In May 1945 in Washington, the Secretary of State for War chaired a committee of scientists which *inter alia* discussed disclosure to Russia and possible forms of international control. Members of the committee were torn between a desire for scientific openness and a conviction that the business could not remain secret for long on the one hand, and by anxieties over deteriorating Russian behaviour on the other hand. The anxieties won and the committee decided early in June 1945 that no information should be revealed to Russia or anyone else until the first bomb had been dropped on Japan [4].

On July 24, eight days after the atomic bomb test at Alamogordo and thirteen days before a bomb was dropped on Hiroshima, President Truman told Stalin simply that the United States had a new weapon of unusual destructive force. Bohr's wartime pleas had failed. As books told about them from the 1960s onwards, they were seen as the remarkable intuition of a remarkable scientist. More recently, a leading historian of international relations, however, attacked them [5]. He wrote:

“the concept of ‘international control’ in the minds of Bohr and others was essentially a cop-out, a flight into higher mysticism away from the unpleasant and unacceptable world of politics.”

Such strictures were inappropriate to Bohr's essentially practical proposal. He knew that Russian physicists were extremely good and that once a bomb was dropped there could be no secret. To inform Russia officially would therefore carry little risk and might conceivably bring benefits. *Not* to inform Russia would bring little benefit and would intensify suspicions. Bohr's idealism, that is, was set in a very practical framework of cost-benefit analysis as he looked to a future when all civilised life might be destroyed in a flash.

If Russia had been told about the bomb during the war it might have made no difference. But she had already begun her own project in 1942 and also knew a great deal about the Manhattan Project from spies. The fact that she was told virtually nothing by the Allies guaranteed that attempts made just after the war to establish international control, which might have failed anyway, were doomed.

Bohr, as I have noted, made no representation in advance about the use of the atomic bomb against Japan, and he did not argue about past events once the war was over. He privately deplored the spirit in which the bomb was used and the opportunities that were lost but he neither made nor joined any written protestations. His thoughts were on the future and the postwar world. With his inbred and unquenchable optimism he was convinced that while atomic bombs introduced unprecedented threats to the world, they also gave a unique opportunity for a new approach to international relationships.

In the spring of 1945 Bohr had written another memorandum looking beyond the question of informing the Russians about the bomb during the war. Bohr warned that the American-British effort, immense though it was, had proved far smaller than might have been anticipated and that any information, however scanty, that might have leaked from it would have greatly stimulated efforts elsewhere. Probably

within the very near future means would be found to

“simplify the methods of production of the active substances and intensify their effects to an extent which may permit any nation possessing great industrial resources to command powers of destruction surpassing all previous imagination. Humanity will therefore be confronted with dangers of unprecedented character unless in due time measures can be taken to forestall a disastrous competition in such formidable armaments and to establish an international control of the manufacture and use of the powerful materials.”

Extraordinary measures would be necessary to counter secret preparations for the mastery of the new means of destruction. Not only must there be universal access to full information about scientific discoveries but every major technical enterprise, industrial as well as military, must be open to international control. The special character of the production of the active materials, and the peculiar conditions governing their use as dangerous explosives, would, said Bohr, greatly facilitate such control and should ensure its efficiency, provided the right of supervision was guaranteed. Detailed proposals for the establishment of an effective control would have to be worked out with the assistance of scientists and technologists appointed by governments and a standing expert committee of an international security organisation might be charged with keeping account of new scientific and technical developments and with recommending appropriate adjustments of the control measures.

On recommendations from the technical committee, the organisation would be able to judge the conditions under which industrial exploitation of atomic energy sources could be permitted, with adequate safeguards to prevent any assembly of active material for an explosive. All material prepared for armaments might ultimately be entrusted to the security organisation to be held in readiness for eventual policing purposes. The prewar bonds between scientists of different nations would be especially valuable in creating controls.

Bohr had foreseen proliferation—that it would be possible for any nation with large industrial resources to command these unimaginable powers of destruction. But he also saw that the special character of the production of fissile material would greatly facilitate efficient control provided that an effective organisation with the right of supervision was established. In all this, his key belief was that there must be openness about scientific discoveries and about industrial and military enterprises.

Elements of Bohr's ideas were to be found in the early postwar proposals for atomic energy control discussed at the United Nations Commission on the subject and, later, in the non-proliferation safeguards to be operated by the International Atomic Energy Agency. However, the United Nations proposals came to nothing and the non-proliferation arrangements did not apply to the existing atomic powers.

On-site inspection, which Bohr regarded as essential to “openness” and which has been an issue in all attempts to control nuclear weapons and installations, has generally been unacceptable to the Soviet Union. However, Bertrand Goldschmidt, who has been continuously involved with atomic energy and with international control since 1940, reminded the Niels Bohr Symposium on Nuclear Armaments of events at the United Nations Atomic Energy Commission in 1946 and 1947. The Soviet Union had made a serious proposal for the establishment of an International

Control Commission to inspect atomic facilities which would, however, still be in national hands. The United States and the Western Powers on the other hand wanted a supra-national authority. There were other problems in the negotiations but in retrospect Goldschmidt believes a unique chance may have been missed since the Soviet Union proposed the maximum opening of their territory which they were ever to put to the international community.

Goldschmidt's paper makes Bohr's proposals for openness less impracticable than they have since appeared. As it was, coming at this early stage of atomic development, the Commission was the first and possibly the last real opportunity for international control. After the funeral of the United Nations Atomic Energy Commission in 1948, openness became *more*, rather than *less*, unthinkable on both sides. Nevertheless, Bohr continued his campaign on every possible occasion. The darker the international outlook grew, the more he was convinced that a great issue, "suited to invoke the highest aspirations of mankind" must be raised. To him this issue was *openness*, with free access to information about all aspects of life in every country. He pleaded that the initiative should be taken—even if the chances of getting agreement were thin—because an offer of openness would strengthen the moral position of the supporters of international co-operation. The opposition of those who refused to join would amount to a confession of lack of confidence in their own cause.

In 1948, Bohr had written in these terms to General Marshall, the United States Secretary of State, urging that America should take the initiative in openness and stressing that this would not entail an a priori commitment to disarmament. His efforts culminated in June 1950 in his Open Letter to the United Nations pleading for

"an open world with common knowledge about social conditions and technical enterprises, including military preparations, in every country."

Like all Bohr's other memoranda, the Open Letter was written with the same examination and re-examination of every word and every nuance that marked his scientific papers. The opaqueness of Bohr's prose may have obscured the message of the Open Letter. However, as it turned out, the prose style probably made little difference. The letter could not have appeared at a worse moment. The Cold War was rapidly intensifying and the Korean War broke out at much the same time. Fear was rampant. Oppenheimer, for one, was deeply pessimistic that anyone in a position of political responsibility would take openness as a basis for action. The Letter brought little public reaction outside Scandinavia and in Britain even the liberal *Manchester Guardian* newspaper wrote unsympathetically that we "must keep our feet on the ground". Rudolf Peierls replied eloquently: "let us also try to keep our heads out of the sand."

Bohr himself remained dedicated to his main theme of openness so much so that he would not weaken it by joining the other peace moves and appeals from men such as Einstein and Bertrand Russell. In 1956 Bohr wrote a further letter to the Secretary of the United Nations, Dag Hammarskjöld.

Looking back on the Open Letter thirty-five years after it was written, I do not think it has ever been considered very seriously except as a moving, albeit unrealis-

tic, expression of idealism. I suggest that on the contrary, the proposal was realistically farsighted. In the war, Bohr had been among the very first to realise that atomic weapons would change the world, that their significance was far greater than their simple but terrifying arithmetical equivalents of thousands of tons of TNT. He quickly appreciated the potential of thermonuclear weapons. He realised that horrific weapons could develop from new advances in biology and chemistry as well as in physics. He also foresaw developments in communications and electronics which would revolutionise information-gathering. Indeed he lived to see Sputnik and missiles.

Above all, he was among the very first to realise that a nuclear arms race has *no logic*. Since a small number of existing atomic weapons are enough to cause unimaginable destruction so that their only rational function is to deter rather than to fight, it is highly undesirable that either superpower should attempt to acquire a quantitative or qualitative lead over the other. Is there not more logic, as well as a bias to peace, in deliberate openness between the nuclear states about their weaponry and its scientific and industrial infrastructure, than in the depressing tales of espionage? It was a very senior intelligence expert who recently said that the greatest danger to the world today is misperceptions caused by lack of proper knowledge.

Experience as well as logic suggests that Bohr was right. The United States McMahon Act of 1946 forbade the transmission of almost all atomic information to any country, including her closest ally Britain, with penalties including death or life imprisonment. Yet ten years later, under the Atoms for Peace programme, much information hitherto considered top secret was positively thrust upon the world and the heavens did not fall. Co-operation has become particularly strong in some areas such as thermonuclear fusion which were once particularly secret. There has been besides the paradox that surveillance through satellite has probably enhanced rather than diminished security.

So, I suggest, Bohr's wartime and postwar view of the nuclear future was hard-headedly realistic as well as clear-mindedly visionary. He himself realised that his open world was a remote possibility in the world of 1950. But who can say that he was wrong when he believed that amidst the stiff technicalities of arms control, which are wellnigh incomprehensible except to the expert, mankind also needs *hope* — as he said, an issue to invoke its highest aspirations.

In short, Bohr showed in his reflections on nuclear weapons the wisdom, imaginative intuition and optimism which informed his science and his whole being.

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