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THE HYDROGEN BOMB AND INTERNATIONAL CONTROL: TECHNICAL AND BACKGROUND INFORMATION

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FOREWORD

In the fall of 1949 the chairman of the joint committee directed the committee staff to study the hydrogen bomb in relation to international control of atomic energy. It is hoped that the following pages, prepared by the staff at the chairman's request, will assist the joint committee in considering this problem. All statements have been meticulously screened so as to include unclassified and publishable information only.

TECHNICAL FACTS OF THE HYDROGEN BOMB RELEVANT TO INTERNATIONAL CONTROL

1. The hydrogen bomb, if it can be made to work, will release energy resulting from the fusion of light elements.

Some years before the fission of uranium was discovered, scientists recognized that if they could find a way to put together light atomic nuclei and make heavier nuclei, energy would be released. Such a reaction can take place when particles collide at high velocity or high relative kinetic energy. Reactions of this kind are believed to occur at the center of the sun and the stars, where the temperature is many millions of degrees centigrade.

2. An A-bomb would be needed to "trigger" an H-bomb.

There are two basic requirements for the hydrogen bomb: (1) An assembly of materials capable of producing a light-element reaction, if sufficiently heated; and (2) a means of heating the materials to the extent necessary. This temperature may be comparable to that existing in the interior of the sun, and today the most promising way to attain such a temperature on earth is through an atomic bomb. Thus, the essential idea is that heavy fissionable material used in A-bombs would explode, thereby heating the hydrogen apparatus, thereby making possible a thermonuclear reaction. The difficulty of inducing such a reaction before the assembly flies apart and while the temperature is adequately high accounts for much of the uncertainty that exists as to whether hydrogen weapons are feasible.

3. Deuterium (i. e., "heavy hydrogen" of mass 2) and tritium (i. e., a "heavy" radioactive hydrogen isotope of mass 3) are suitable materials for the H-bomb.

The scientific evidence is clear that normal hydrogen of mass 1 would not contribute basically to an H-bomb. But the two heavy hydrogens, deuterium and tritium, are of fundamental interest. There are three possible reactions involving the heavy hydrogens: (1) A deuterium-deuterium reaction (i. e., two nuclei of deuterium fusing to produce tritium, a proton, and energy or helium, a neutron, and energy); (2) a tritium-tritium reaction (i. e., two nuclei of tritium fusing to produce helium, two neutrons, and energy); and (3) a tritium-deuterium reaction (i. e., a nucleus of tritium and a nucleus of deuterium fusing to produce helium, a neutron, and energy).

4. Deuterium is obtainable through conventional industrial operations.

Deuterium may be isotopically separated from hydrogen as found in nature. In addition, "heavy water"—so-called because it contains "heavy hydrogen" or deuterium—has been manufactured on a considerable scale. The process of chemically separating the deuterium from oxygen in heavy water is a relatively simple one. Heavy water has long been known to be useful as a research material and as a neutron moderator and coolant for reactors.

5. Tritium may be produced in nuclear reactors (like those at Hanford) by neutron bombardment of lithium, a light metallic element.

All large reactors produce neutrons in quantity. These neutrons are ordinarily used to create plutonium, but they can be used alternatively to create tritium. If lithium—the lightest metallic element—is placed inside a reactor and bombarded with neutrons, it breaks down into a mixture of helium 4 and tritium. These can be separated without excessive difficulty.

6. It might be possible to construct an H-bomb whose blast damage in a circle of 10 miles radius would be comparable to that which occurred at Hiroshima in a circle of 1 mile radius.

There have been numerous references to the great energy released from an H-bomb. It has been stated that it might be a thousand times greater than that of a fission bomb. The "critical size" effects which primarily limit the energy release from A-bombs do not apply to H-bombs. The range of destructive blast effect would be increased many times over that of an A-bomb.

Heat effects may also be considerably increased, although these effects will be variable and uncertain since they will depend on atmospheric conditions. Ordinarily the hazards of nuclear radiations and radioactive contaminants from an H-bomb would not be significant in comparison with the blast and heat effects, although it might be possible so to design and use an H-bomb that dangerous contamination would be produced locally.

A COMPARISON OF A-BOMBS AND H-BOMBS IN RELATION TO INTERNATIONAL CONTROL

1. Uranium, the raw material basic to A-bombs, is scarce and expensive, whereas hydrogen and lithium, raw materials basic to H-bombs, are abundant and reasonably cheap.

Uranium is a heavy metallic element rarely found in concentrated deposits in the earth's crust. Ordinary hydrogen, from which the heavy isotope deuterium may be derived, is obtainable in almost unlimited quantities from a number of industrial processes—for example, as a byproduct in the production of fertilizer. Lithium, which gives tritium if bombarded by neutrons in a nuclear reactor, frequently occurs in concentrated deposits; and mining costs are not excessive. Uranium, however, is also needed for H-bombs, since it furnishes the fissionable materials necessary to "trigger" a thermonuclear reaction.

2. U–235 and plutonium, the fissionable materials needed for A-bombs and as "triggers" for H-bombs, are costly and difficult to produce. Deuterium, one H-bomb ingredient, can be manufactured fairly easily and cheaply; but tritium, another H-bomb ingredient, resembles plutonium in that production requires neutrons, may take place within reactors, and involves marked expense.

Dr. Robert F. Bacher, a noted physicist and former member of the Atomic Energy Commission, has commented on tritium production as follows:

> It would be necessary, of course, to know * * * about the actual workings of a nuclear reactor in order to say just how much tritium could be produced in that reactor if one were willing to forego the production of a certain amount of plutonium. It sounds as if the production of tritium in quantity is at least a fairly expensive, if not formidable process.

To the cost of deuterium and tritium must be added the cost of fissionable materials required for "triggering" purposes.

3. U–235 and plutonium have half-lives of thousands of years, whereas tritium has a half-life of about 12 years.

Fissionable materials are the first weapon components in history which can never, for practical purposes, become obsolete. The assembly used to detonate them may change, but they themselves remain chemically the same whether inserted in a Hiroshima-type atomic bomb or in an improved Eniwetok-type bomb. Half of a quantity of tritium, in contrast, decays to helium 3 after about 12 years.

4. U–235 and plutonium, key A-bomb materials, have immense potential peacetime value as reactor fuels, whereas the constructive uses of deuterium and tritium, except on a laboratory scale, appear to be limited or nonexistent.

Heavy water containing deuterium is of interest, both as a moderator and as a coolant in certain types of nuclear reactors. It is possible, however, that the reactors which may ultimately propel ships and airplanes and furnish industrial power will not be dependent upon heavy water. Tritium, aside from its considerable value in laboratory quantities, has no known or foreseeable peacetime uses as a source of power.

5. A considerable stockpile of A-bombs is in existence today, whereas H-bombs have not yet been brought into existence.

When the United Nations first considered international control of atomic energy, it was faced with the problem of suppressing a weapon already in existence and already an accomplished fact. Its task, in a sense, was to undo what had been done. If an effective control agreement is more easily reached regarding a weapon not yet an accomplished fact—if it is easier never to do what is still undone, rather than to undo what has been done—an opportunity may now exist that will pass if and when the H-bomb becomes a reality.

Example: Since quantities of fissionable material are in existence today, there is the problem of making sure that each nation—at the time a control plan takes effect—actually discloses all the fissionable material which it has manufactured and does not secretly conceal a portion while pretending to have revealed its entire stockpile. This problem intensifies as time passes and as more and more fissionable material comes into being in the absence of a control plan. But the same problem as regards deuterium and tritium is clearly less acute today than it will be later.

POSSIBLE QUESTIONS REGARDING H-BOMBS AND INTERNATIONAL CONTROL

The answers to many of the questions which follow are obvious. The answers to other questions are less obvious. Each question has been selected to suggest and to illustrate the kind of problem which may be involved, whether easy or difficult of solution. It should be emphasized that the original United States proposals and the existing United Nations plan foresee and carefully take into account the possibility of an H-bomb, as evidenced by the language they contain. The same is true of the McMahon Act for domestic control of atomic energy within the United States.

1. Is the hydrogen bomb a more or less important weapon than the atomic bomb? Might hydrogen bombs prove to be decisive in war, or has their significance been exaggerated?

Dr. Harold Urey, a Nobel Prize winner in physics, has suggested that the H-bomb would be militarily decisive; Dr. Hans Bethe, another noted physicist, has indicated that the step from A-bombs to H-bombs is as great as the original step from conventional to atomic explosives. However, Dr. Robert F. Bacher, a former AEC Commissioner, states that—

> while it [the H-bomb] is a terrible weapon, its military effectiveness seems to have been grossly overrated in the minds of laymen.

Some of the questions which may bear upon this difference of opinion are as follows:

(1) *Shock effect.*—To what extent do H-bombs excel A-bombs in permitting a highly destructive attack to be compressed in time?

(2) *Comparative numbers.*—What quantity of A-bombs are required to do the same job as a given number of H-bombs?

(3) *Neutron economy.*—How much fissionable material for A-bombs is sacrificed by using the neutrons available in reactors for making H-bomb materials?

(4) *Deliverability.*—Under various combat conditions, is the delivery of H-bombs cheaper and surer than delivery of an "equivalent" number of A-bombs?

(5) *Aiming accuracy.*—How superior is a weapon which need strike only within a number of miles in order to destroy its target over one which must strike within 1 or 2 miles?

(6) *Psychology.*—As compared with the A-bomb, to what extent might the H-bomb impair an enemy's will to resist and accelerate recognition of defeat?

(7) *Tactical employment.*—What is the relative value of A-bombs and H-bombs in tactical situations—when used against troops in the field, guerrilla fighters, forces preparing for amphibious invasion, a fleet, a string of air strips or submarine bases, atomic facilities, underground installations, etc.?

(8) *Definition of "military effectiveness".*—Would the use of H-bombs to destroy large urban centers containing no armaments plants have no "military effectiveness," or would such destruction aid the attacker and therefore represent "militarily effective" use of the weapon? Is it possible to distinguish, in an era of total war, between "military" and "nonmilitary" targets?

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2. If the H-bomb is deemed to be decisive or far more dangerous than the A-bomb, should international control of hydrogen weapons take priority over control of ordinary atomic weapons? Should the United States propose a separate plan exclusively designed to regulate H-bombs?

The official United Nations proposals for international control of atomic energy apparently involve the assumption that A-bombs are so unique technically and so menacing as to set them apart from conventional weapons and to justify separate consideration in the United Nations and a separate regulatory system. If the step from A-bombs to H-bombs is considered to be as great as the step from conventional weapons to A-bombs, does it follow that hydrogen warfare should become the subject of a separate control proposal and should receive separate consideration in the United Nations?

Are the technical facts of atomic and hydrogen weapons so intimately related that both must be controlled if either is to be controlled? Are the political facts such that the two problems must be regarded inseparably?

3. Is the existing United Nations plan technically adequate to control H-bombs?

The United Nations plan has been couched in such a manner that an international agency would possess discretionary authority in defining and controlling materials and processes that may be employed to manufacture nuclear weapons of mass destruction.

For instance, the *Second Report* of the United Nations Atomic Energy Commission defines "atomic energy" as including "all forms of energy released in the course of, or as a result of, nuclear fission *or of other nuclear transformation.*" "Source material" is taken to mean "any material containing one or more key substances in such concentration as the international agency may by regulation determine." "Key substance" is defined to mean "uranium, thorium *and any other element from which nuclear fuel can be produced, as may be determined by the international agency.*" (p. 71). Similarly, the report defines "nuclear fuel" as "plutonium, U–233, U–235, uranium enriched in U–235, material containing the foregoing, *and any other material which the international agency determines to be capable of releasing substantial quantities of atomic energy through nuclear chain reaction of the material.*" (p. 71). The *report* likewise observes that: "Dangerous activities or facilities are those which are of *military significance* in the production of atomic weapons. The word 'dangerous' is used in the sense of *potentially dangerous to world security.*" (p. 70). [Italics supplied throughout.]

Does such breadth of phraseology mean that manufacturing processes and source materials needed in the production of H-bombs could be properly controlled through the existing UN plan?

Since nearly 2 years of work were required to formulate the UN plan, can this plan be regarded as adequate for hydrogen weapons so long as the control measures for the atomic energy industry are not explicitly elaborated with the same detail as the arrangements evolved for controlling U–235 and plutonium?

It may also be pointed out that the existing UN plan contains no provision for physically protecting informants who advise the international agency of violations. Might potential informants keep silent for fear of being punished by their national governments? Is this factor important if the existing UN plan were subjected to the added strain of controlling hydrogen weapons as well as atomic weapons?

What safeguards would assure that the employees of an international control agency would be faithful and loyal to the objectives of the agency and that they would not work purely in the interests of some national government—perhaps a national government other than that of their own country?

4. Is control over fissionable materials sufficient to prevent the production of hydrogen bombs? If so, is the existing UN plan adequate to this task?

The technical facts suggest that H-bombs may be regulated in at least two ways: (1) Control over the fissionable material usable as a "trigger" and (2) control over deuterium and tritium.

Perhaps control over *all* fissionable material would give effective control over hydrogen weapons. However, by way of specific example, the introduction to volume VI of the Scientific Information Transmitted to the United Nations Atomic Energy Commission, June 14, 1946–October 14, 1946 (see State Department Publication 2661, pp. 151–152), comments as follows:

It is difficult to define the amount of activity in the illicit production of atomic weapons which is significant. The illicit construction of a single atomic bomb by means of a decade of successful evasion would not provide an overwhelming advantage, if it can be assumed that it would take another decade to produce a second bomb. But the secret production of one bomb per year would create a definite danger, and the secret production of five or more per year would be disastrous. This report assumes arbitrarily that the minimum unit of noncompliance is the secret production of one atomic bomb per year or a total of five bombs over any period of time. [This example is chosen because UN documents published later omit concrete illustrations, although the stress which these documents place upon international ownership, operation, and management clearly reflects a determination to reduce to the rock-bottom minimum any illicit mining or production.]

Considering that five illicit A-bombs might, under certain circumstances, lead to five illicit H-bombs, what margin of inefficiency—if any—in controlling source and fissionable material is permissible? Is absolute protection against illegal diversion of source and fissionable material technically possible? Does the existing UN plan provide absolute or near-absolute protection? Can greater technical protection be secured than under the present UN plan?

5. Must H-bomb controls relate to deuterium and tritium as well as to fissionable material? If they must, can the present UN plan fully provide for these controls or does it require revision or changes in emphasis?

Should control over both fissionable material and deuterium and tritium call for the same emphasis and consideration which the United Nations Atomic Energy Commission has already given to control of U–235 and plutonium? Would surveillance of deuterium and tritium manufacture furnish better insurance against illicit H-bomb construction than surveillance of U–235 and plutonium, or is the reverse more apt to be true? Are added safeguards necessary to regulate deuterium and tritium? Or is the UN plan, as now constituted, sufficiently flexible and comprehensive to take care of light-element control?

6. Is it technically possible to detect the manufacture of heavy water and deuterium through international inspection? Would an international agreement flatly prohibiting production in quantity be desirable?

The manufacture of heavy water and the separation of deuterium are relatively simple processes. They may be carried out in small plants which can exist in a variety of locales.

The *Second Report* of the UN Commission comments as follows:

> The international agency shall have the authority to require periodic reports from nations regarding the production, shipment, location, and use of specialized equipment and supplies directly related to the production and use of atomic energy, such as mass spectrometers, diffusion barriers, gas centrifuges, electromagnetic isotope separation units, very pure graphite in large amounts, heavy water, and beryllium or beryllium compounds in large amounts. In addition, the agency shall have authority to require reports as specified of certain distinctive facilities and construction projects having features of size and design, or construction or operation, which, in combination with their location and/or production or consumption of heat or electricity, are peculiarly comparable to those of known atomic facilities of dangerous character (p. 54).

Would inspectors possessing freedom of movement be able to locate deuterium and heavy water plants? Would aerial surveys and aerial photographs of industrial areas help detect processes which produce hydrogen as a byproduct and which might therefore be concerned with the manufacture of heavy water or deuterium? Should quantity production of deuterium be prohibited even though it is used in certain types of peacetime reactors such as the Canadian reactor at Chalk River, the French reactor at Chatillon, Swedish reactors under construction, and a research reactor at the Argonne National Laboratory? Is it possible on technical grounds to enforce such a prohibition?

7. Should the provisions of the present UN plan relating to inspection, surveys, and explorations be modified to control heavy water and deuterium production?

The United Nations plan assumes that the production of fissionable material cannot be regulated without strict supervision over the mining of source materials such as uranium and thorium:

> Without the control of raw materials, any other controls that might be applied in the various processes of atomic energy production would be inadequate because of the uncertainty as to whether or not the international agency has knowledge of the disposition of *all* raw material. (*Second Report*, p. 30.)

Whereas uranium and thorium are needed to produce U–235 and plutonium, the production of deuterium is not subject to such limitation of source materials. Only water, the existence of power, and comparatively simple plants are needed for the manufacture of heavy water and deuterium. In view of these facts, can the existing United Nations plan cope with the problem of regulating deuterium production?

In commenting upon spot aerial surveys, for example, the Second Report recommends that "the [international] agency shall conduct spot aerial surveys in each period of 2 years over areas not exceeding

5 percent of the territory under the control of each nation or areas not to exceed 2,000 square miles, whichever is the larger. (These area limitations apply to spot aerial surveys only)" (p. 68). If aerial surveys were to be used not only in controlling raw materials but also to help in spotting deuterium and heavy water plants, must they be carried out more frequently than is provided in the existing plan?

The *Second Report* also indicates that a UN inspectorate should be compelled to secure permission, through a warrant procedure, before inspecting "private and restricted property not open to visitation by the population in the locality, and in the case of certain ground surveys and aerial surveys which are additional to others which the agency may conduct without warrant or other special authorization" (p. 60). Do the technical facts surrounding heavy water and deuterium production suggest that such a restriction on an international agency's authority would have to be modified?

8. What safeguards are necessary to prevent clandestine production of tritium? Would an international agreement flatly prohibiting production in quantity be desirable?

U–235 and plutonium may be used either in weapons or as fuels for peacetime reactors. Here is the reason most frequently cited for requiring that international control include not only inspection but also such further guaranties as United Nations ownership, operation, and management of "dangerous" plants. The potentiality, both for good and evil, that characterizes fissionables does not appear to characterize tritium, which has no known peacetime uses except as a laboratory research tool. Is it therefore possible that the reason for requiring inspection plus other guaranties as regards U–235 and plutonium does not apply to tritium and that inspection alone would answer?

If quantity production of tritium were altogether forbidden—as having no peacetime purpose—the mere act of preparing lithium (the tritium raw material) for irradiation and the mere act of inserting it in a nuclear reactor might be considered a violation. Would such action be impossible to conceal from managers and inspectors stationed at each reactor permitted under the control agreement? Would an illegal reactor itself be impossible to conceal from inspectors enjoying freedom of movement?

A few private commentators have argued that the UN plan fundamentally errs in assuming industrial power to be around the corner. They estimate that this goal is actually a decade or two away and that meanwhile the control problem would be simplified if all high-powered reactors were dismantled. Does the role of reactor-produced tritium in H-bomb production strengthen such an argument?

The UN plan distinguishes between atomic facilities which are sufficiently "dangerous" to require UN management and facilities which may be operated by national governments and merely require international inspection. Since all reactors produce neutrons and hence might be useful in some degree—however small—in manufacturing tritium, is it now necessary to regard certain reactors formerly considered to be "non-dangerous" as now being in the "dangerous" category?

Are there other methods, apart from reactors, for producing tritium? If so, how can they be controlled? Would the right of the international control agency to own, operate, and manage "dangerous" plants and to own and regulate both fissionable materials and "fusionable materials" meet such a situation?

9. Should a world-wide geological survey cover concentrated lithium deposits?

A key feature of the United Nations plan is the provision for a world-wide geological survey of uranium and thorium—the raw materials potentially usable in A-bombs. This survey is considered necessary in order to permit tracing of materials as they progress from the mines through various processing phases and finally enter a nuclear reactor. Does the same kind of logic apply to lithium—raw material for tritium? How formidable is the technical problem of locating and controlling deposits of lithium?

Pegmatite minerals constitute a principal source of lithium ores, which are currently produced as a byproduct of the nonmetallic mineral industry. Commercial deposits of lithium are known to exist in the Black Hills of North Dakota; northern New Mexico; Saskatchewan, Canada; and southwest Africa. Production of ores rose to about 900 tons of lithium oxide in 1944 and is now about 200 tons. So long as requirements do not exceed byproduct production, supply does not appear to present a problem. If requirements exceed byproduct supply, the cost of the excess might be high. Lithium is now used commercially in glass, as a compound in welding fluxes, in storage batteries, in fluorescent light tubes, and as an alloying element.

Are the quantities of lithium ore required on an order of magnitude that makes control feasible?

10. Do the technical facts of the H-bomb mean that now, more than ever, the United Nations plan is the correct approach to international control?

Various critics of the UN plan have denied that management control over "dangerous" plants is essential to protect against violations. High-power reactors are among the plants to be classified as "dangerous" under the UN plan, and these same reactors are the ones which might produce not merely plutonium but tritium in quantity. Likewise, an international agency would possess authority to check the design of any isotope separation unit and to assume the right of construction and operation if these fall into the "dangerous" category. Deuterium may be obtained through isotopic separation. Do such facts as these refute the critics and demonstrate that managerial and material control by the United Nations, over and above inspection, is more than ever necessary in order to prevent diversion of nuclear fuel or illegal irradiation of lithium?

11. How does the H-bomb affect the problem of "stages"?

The United Nations plan would take effect by "stages"—one stage to include, among other projects, a world-wide geological survey, another stage to involve, among other projects, the taking over of atomic installations, and still another to bring about the disposition of fissionable materials.

At what point in some such progression would national stockpiles of deuterium and tritium be placed under control? When this point was reached, would they be destroyed or be held in storage under United Nations auspices? If a nation pretended to make known its entire stockpile of tritium and deuterium while actually it kept hidden a substantial portion, how would the international agency discover such a violation?

12. How does the H-bomb bear upon the problem of disposition of existing stocks of fissionable material?

When a control plan takes effect, what should be done with supplies of U–235 and plutonium in excess of a quantity immediately usable for peacetime purposes? This problem has received relatively little consideration in the United Nations Atomic Energy Commission. If excess stocks were destroyed, a valuable future source of energy and storehouse of neutrons would be lost. On the other hand, if the stocks were kept in existence under UN guard, seizure by an aggressor state might rapidly permit it to attack with atomic bombs—and innocent countries might have relatively little warning.

Such seizure might quickly lend, under certain circumstances, to the construction of "triggers" for H-bombs. Does this fact tip the balance in favor of destroying excess U–235 and plutonium? Or are these substances still too valuable and too difficult to replace to justify destruction? Is there a third alternative—possibly involving partial destruction or the use of "denaturants" or the construction of many power reactors, regardless of cost factors—to keep excess stocks of fissionables contaminated with fission products?

13. How does the H-bomb bear upon "quotas"?

The United Nations plan envisages that reactors and other atomic facilities will be distributed among the nations according to "quotas" and a "strategic balance"—whereby no one nation, by seizing the plants within or near its borders, could gain an undue military advantage over innocent nations. This "quota" feature has been criticized as unnecessary and as likely to hinder individual countries in developing the peacetime uses of atomic energy to the maximum extent.

Does the fact that reactor fuels, if seized by an aggressor, might make available H-bomb "triggers" tend to render all the more desirable the "quota" idea? How long a time would an aggressor require to make enough deuterium and tritium for H-bombs in seized plants? Could a world-control authority, by requiring that certain design features be incorporated in the plants under its control, extend this time period? What should be done with plants in existence at the time a control agreement takes effect and well suited to H-bomb production but poorly suited to peacetime uses? How should such plants, if they were not dismantled, figure in "quota" allotments?

14. How does the H-Bomb bear upon research to be performed by the United Nations control agency?

Under the United Nations plan, individual nations would be forbidden to engage in atomic weapons research, but such research would be performed by the world control agency itself, as a means of keeping it at the forefront of knowledge in this field and thereby enabling it to detect violations which might otherwise pass unnoticed through ignorance. Is research upon H-bombs so dangerous that not even the world control agency should be allowed to undertake it?

15. Should technical information regarding the H-bomb be transmitted to the United Nations as a basis for a discussion of hydrogen control?

In 1946, the United States transmitted six volumes of technical information on atomic energy to the United Nations. This was one important means of providing members of the United Nations Atomic Energy Commission with sufficient basic data to discuss international control.

No similar body of material on hydrogen bombs has been transmitted to the United Nations. Can the Commission now discuss the control of hydrogen warfare without further official information on its technical aspects? If such information is to be provided, who should be the provider, the United States or the Soviet Union, or both?

16. Should a new panel of experts analogous to the Acheson-Lilienthal Board be appointed to study the H-bomb in relation to international control?

It is now more than 4 years since the Acheson-Lilienthal Board made its recommendations on international control. Their findings have since been largely incorporated into the UN plan.

Do the events of the last 4 years make it desirable, for technical reasons, to rethink the control problem? Are the technical data of hydrogen bombs, such as to demand a recasting and change of emphasis in the existing UN plan? Have the prospects of large-scale peacetime applications of atomic energy sufficiently changed that a different orientation in control measures is desirable?

If reexamination of the control question is indicated, should this inquiry be undertaken in the first instance by a group of qualified Americans? Or should the United States suggest that an internationally constituted board initially take on this assignment?

Considering strong Soviet opposition to the UN plan, is it useful to consider the problem of control? Is the Soviet attitude at all likely to change in the foreseeable future? Would a rethinking of the control problem contribute to a solution unless Soviet representatives participated? Would the appointment of a new "Acheson-Lilienthal Board" raise false hopes?

SIGNIFICANT EVENTS IN THE HISTORY OF INTERNATIONAL CONTROL OF ATOMIC WEAPONS

May 1945: Secretary of War Stimson appoints interim Committee to study problem of atomic energy.

August 6, 1945: Hiroshima.

October 3, 1945: President's message to Congress outlines necessity for international control of atomic energy and proposes conversations with Canada and United Kingdom.

November 15, 1945: Three-nation agreed declaration on atomic energy (Truman-Attlee-King declaration). Calls for United Nations Commission to make proposals for international control plan. Proposals should provide safeguards "by way of *inspection and other means*." [Wherever used in the following pages, italics are supplied.]

December 27, 1945: U. S.-U. K.-U. S. S. R. Foreign Minister communiqué on results of Moscow Conference. Proposes that Canada, China, and France join with Big Three in sponsoring resolution calling for United Nations Atomic Energy Commission with terms of reference stipulated in Truman-Attlee-King declaration.

January 24, 1946: General Assembly resolution establishing United Nations Commission on Atomic Energy. Composed of members of Security Council plus Canada.

March 28, 1945: Acheson-Lilienthal report. Urges that mines and "dangerous" atomic-energy facilities be put under *international ownership* and *management* of Atomic Development Authority. Additional safeguards in the form of *inspection*. Nations to operate only "safe" plants under ADA license. Plants to be distributed among nations in keeping with *strategic balance*. Control plan to be implemented by *stages*.

June 14, 1946: Baruch proposals to United Nations. Closely follow Acheson-Lilienthal recommendations. Ask "condign punishment" for violations, and request agreement that UN Charter *veto* clause not apply to sanctions for stipulated violations of atomic-energy treaty.

June 19, 1946: Soviet Union counterproposals. Demand prohibition of atomic weapons and destruction of existing stockpiles *before* international control plan is negotiated. Soviet proposals provide no safeguards against evasion.

December 31, 1946: First Report of UNAEC. Incorporates essential features of Baruch proposals into statement of principles for plan for international control of atomic energy. Adopted 10 to 0, with U. S. S. R. and Poland abstaining.

June 11, 1947: U. S. S. R. control proposals. Soviets assent to *periodic inspection*, but this would apply only to *declared* plants.

August 11, 1947: Soviets consent in principle to concept of *quotas*.

September 11, 1947: Second Report of UNAEC. Outlines powers, functions, and limitations thereon of any international agency in implementing effective control plan.

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May 17, 1948: Third Report of UNAEC. Reports impasse because Soviets refuse to accept majority plan and persist in refusing to put forward effective proposals of their own. Concludes that further work in UNAEC is fruitless until Soviet cooperation in broader fields of policy is secured. Recommends that Commission's work be suspended until sponsoring powers find that basis for agreement exists.

September 25, 1948: Soviets modify position by asking that conventions for prohibition of atomic weapons and for international control go into effect simultaneously.

November 4, 1948: By vote of 40 to 6, UN General Assembly endorses majority control plan. Calls upon UNAEC to continue work and requests that sponsoring powers consult to explore possible basis of agreement.

August 9, 1949: First meeting of sponsoring powers of UNAEC.

September 23, 1949: President Truman's announcement of Soviet atomic explosion.

October 25, 1949: Canada, China, France, United Kingdom, United States statement reveals Soviet attitude still prevents agreement.

November 23, 1949: General Assembly resolution calls upon sponsoring powers to continue consultations.

November 23, 1949: Soviets reverse position on quotas, abandoning previous assent in principle.

January 19, 1950: U. S. S. R. walks out of sponsoring powers consultations over China recognition issue.

January 31, 1950: President Truman announces that United States will proceed with development of hydrogen bomb.

THE INTERNATIONAL CONTROL OF ATOMIC WEAPONS: A BRIEF HISTORY OF PROPOSALS AND NEGOTIATIONS

Early steps looking toward international control

Even before the test explosion at Alamagordo, N. Mex., had ushered in the atomic age, the United States Government was studying methods of making atomic energy a socially constructive force.

In May 1945 an Interim Committee appointed by Secretary of War Stimson commenced investigating the problem. The Committee recognized "that the means of producing the atomic bomb would not forever remain the exclusive property of the United States * * *." Therefore, "Secretary of War Stimson was one of the first to recommend a policy of international supervision and control of the entire field of atomic energy * * *."

When on August 6, 1945, President Truman made the first public statement on the atomic bomb, he made clear that "under present circumstances it is not intended to divulge the technical processes of production or all the military application, pending further examination of possible methods of protecting us and the rest of the world from the danger of sudden destruction." He assured the American people that he would "make further recommendations to the Congress as to how atomic power can become a powerful and forceful influence toward the maintenance of world peace."

The President's recommendations were transmitted to the Congress on October 3, 1945. He spoke of the necessity for "international arrangements looking, if possible, to the renunciation of the use and development of the atomic bomb, and directing * * * atomic energy * * * toward peaceful and humanitarian ends." So great a challenge could not await the full development of the United Nations. The President, therefore, proposed initiating discussions "first with our associates in this discovery, Great Britain and Canada, and then with other nations * * *."

The Truman-Attlee-King declaration

In the three-nations agreed declaration of November 15, 1945—frequently called the Truman-Attlee-King declaration—was recorded the concerted objectives of the three nations that had developed the atomic bomb.

According to the declaration, any international arrangements should have a dual goal: Preventing the use of atomic energy for destructive purposes, and promoting its use for peaceful and humanitarian ends. To reach these objectives, the signatory nations proposed a United Nations Commission empowered to make recommendations to the parent body. It was asked that the Commission make specific proposals "for effective safeguards by way of inspection and other means to protect states against the hazards of violations and evasions." It was further suggested that the Commission's work "proceed by separate stages, the successful completion of each of which will develop the necessary confidence of the world before the next stage is undertaken."

Contained in the agreed declaration was the genesis of the basic feature of the control proposals subsequently advanced by the United States, and accepted by a large majority of the United Nations: safeguards through inspection and *other means*. It was recognized even at this early date that "effective, reciprocal, and enforceable safeguards" against evasion represented the minimum prerequisite of a satisfactory international arrangement.

At the Moscow meeting of the Council of Foreign Ministers, held in December 1945, the Truman-Attlee-King proposals received the Soviet Union's endorsement. The United States, Great Britain, and the Soviet Union agreed to invite Canada, China, and France to join with them in sponsoring a resolution calling for a United Nations Atomic Energy Commission. Such a Commission would consist of the 11 members of the Security Council plus Canada when that state was not sitting on the Council. It is noteworthy that the Commission's proposed terms of reference were exactly those suggested by the Truman-Attlee-King declaration.

In its first substantive resolution, the United Nations General Assembly unanimously adopted the recommendations of the Moscow Conference and established the United Nations Commission on Atomic Energy on January 24, 1946.

The Acheson-Lilienthal report

In order to inquire into the nature of the "effective, reciprocal, and enforceable safeguards" called for in the Truman-Attlee-King declaration, Secretary of State Byrnes in January 1946 appointed a Committee headed by Under Secretary of State Dean Acheson. The Committee in turn enlisted the aid of a Board of Consultants under the chairmanship of David Lilienthal.

The findings of the two groups were made public on March 28, 1946, in the Report on the International Control of Atomic Energy, commonly called the Acheson-Lilienthal report. It was advanced "not as a final plan but as a place to begin, a foundation on which to build."

The report concluded that no security against atomic attack could be found in an agreement that merely "outlawed" these weapons. Nor was it considered feasible to control atomic energy "only by a system which relies on inspection and similar policelike methods." Instead, inspection must be supplemented by *international ownership and management* of raw materials and key installations. "Dangerous" operations—those of potential military consequence—would be carried out by an Atomic Development Authority, an international agency under the United Nations. Only "safe" activities—those of no military importance—would be conducted by the individual nations, under licenses from the Atomic Development Authority. Any plan finally agreed upon would be implemented by *stages* with the United States progressively transferring its fund of theoretical and technological knowledge to an international authority as safeguards were put into effect.

The report amplified the Truman-Attlee-King proposals in two important respects.

First, it stated that international ownership—not specifically mentioned in the earlier declaration—was a necessary adjunct of international inspection. Second, it advanced the concept of "strategic balance" or "quotas." The Report held that an acceptable plan must be "such that if it fails or the whole international situation collapses, any nations such as the United States will still be in a relatively secure position, compared to any other nation." To help attain this end, it was proposed that the Atomic Development Authority's stock piles and plants be well distributed geographically.

The Baruch proposals to the United Nations

Less than 3 months after the publication of the Acheson-Lilienthal report, the United States Government gave the world its proposals for the international control of atomic energy. On June 14, 1946, Bernard Baruch presented them to the United Nations Atomic Energy Commission "as a basis for beginning our discussion."

Mr. Baruch stated that:

"When an adequate system for control of atomic energy, including the renunciation of the bomb as a weapon, has been agreed upon and put into effective operation and condign punishments set up for violations of the rules of control which are to be stigmatized as international crimes, we propose that:
"1. manufacture of atomic bombs shall stop;
"2. existing bombs shall be disposed of pursuant to the terms of the treaty; and
"3. the Authority shall be in possession of full information as to the know-how for the production of atomic energy."

The methods suggested for achieving international control were the following:

The United States proposes the creation of an International Atomic Development Authority, to which should be entrusted all phases of the development and use of atomic energy, starting with the raw material and including—

1. Managerial control or ownership of all atomic energy activities potentially dangerous to world security.
2. Power to control, inspect, and license all other atomic activities.
3. The duty of fostering the beneficial uses of atomic energy.
4. Research and development responsibilities of an affirmative character intended to put the Authority in the forefront of atomic knowledge and thus to enable it to comprehend, and therefore to detect—misuse of atomic energy. To be effective, the Authority must itself be the world's leader in the field of atomic knowledge and development and thus supplement its legal authority with the great power inherent in possession of leadership in knowledge.

These proposals represented a broadening—rather than essential modification—of the Acheson-Lilienthal recommendations. The additional features concerned (1) *condign punishment,* and (2) the so-called power of veto of the United Nations Charter.

Whereas the Acheson-Lilienthal report had not dealt with the subject of sanctions, Mr. Baruch held that a realistic agreement must provide for penalties "of as severe a nature as the nations may wish and as immediate and certain in their execution as possible * * *." Such "condign punishment" would be meted out if *previously stipulated* violations of a control plan occurred.

This problem, Mr. Baruch stated, was intimately related with the veto provisions of the United Nations Charter. Under the Charter, sanctions can be invoked only with the concurrence of the five permanent members of the Security Council, i. e., China, France, United Kingdom, United States, and the Soviet Union. Mr. Baruch maintained, however, that "there must be no veto to protect those who violate their solemn agreements not to develop or use atomic energy for destructive purposes * * *. The bomb does not wait on debate." He pointed out that the United States was "concerned here with the veto power only as it affects this particular problem."

A United States memorandum of July 12, 1946, stressed that "Voluntary relinquishment of the veto on questions relating to a specific weapon previously outlawed by unanimous agreement because of its uniquely destructive character, in no wise involves any compromise of the principle of unanimity of action as applied to general problems or to particular situations not foreseeable and therefore not susceptible of advance unanimous agreement."

The first Soviet proposals—Gromyko's statement of June 19, 1946

A week after the American plans were put forward, the Soviet Union announced its own proposals. They were marked chiefly by Soviet insistence that the United States agree to stop the production of atomic weapons and destroy existing bombs *before* international control arrangements were negotiated.

Although they called for "an international convention for outlawing weapons based on the use of atomic energy," the Soviet proposals did not provide "effective safeguards by way of inspection and other means to protect complying states against the hazards of violations and evasions." They proposed that the "rule of unanimity" in the Security Council apply to atomic-energy matters. Hence if one of the permanent members of the Security Council or a friend violated a control scheme, the other members of the United Nations would have no legal means, under the Charter, of invoking sanctions against it.

Throughout 1946 the United Nations Atomic Energy Commission continued its investigation of the control problem. On December 31, 1946, the Commission issued its *First Report*. It revealed that the essential features of the Baruch proposals had won the support of all the members of the Commission except the Soviet Union and Poland.

The Soviet proposals of June 11, 1947

A year after it suggested a convention for "outlawing" atomic weapons, the Soviet Union came forward with a set of control proposals.

A chief point of interest in the plan was the fact that the Soviets now assented to "*periodic* inspection of facilities for mining and production of atomic materials" by an international inspectorate. In answer to a United Kingdom inquiry, however, the Russians stated that "normally, inspectors will visit only *declared* plants"—with this supplemented by special investigations when there were "grounds for suspicion" of violation of the convention for the prohibition of atomic weapons. The power of the Control Commission would be further limited to making recommendations to governments and to the Security Council. On other matters that separated the Soviet Union from the majority position—such as international ownership and management, and the veto question—there was no change in the Russian position.

The subsequent half-year brought one sign of a further modification of the U.S.S.R. stand. On August 11, 1947, Mr. Gromyko seemingly brought the Soviets closer to the majority position by agreeing that "the idea of quotas deserves attention and serious consideration by the Atomic Energy Commission * * *."

The Second and Third Reports of the United Nations Atomic Energy Commission—September 11, 1947, and May 17, 1948

The *Second Report* of the Atomic Energy Commission spelled out in detail the precise powers and functions and the limitations thereon of any international agency in implementing an effective control plan. When the *Report* was approved by the General Assembly by a vote of 40 to 6, the plan developed in the UNAEC became a world plan—to which only the Soviet Union and her satellites took exception.

By the spring of 1948 the UNAEC became convinced that the Soviet Union's refusal to accept any plan that met the technical requirements of controlling atomic energy was symptomatic of broader differences which made further negotiations on the Commission level fruitless.

The *Third Report* stated that "the majority of the Commission has been unable to secure the agreement of the Soviet Union to even those elements of effective control from the technical point of view, let alone their acceptance of the nature and extent of participation in the world community required of all nations in this field * * *."

It appeared to the Commission that the atomic deadlock was but one manifestation of the more widespread dispute between the Soviet Union and the rest of the world. In view of this, the Commission majority recommended that negotiations in the Commission be suspended until the permanent members of the UNAEC found that "there exists a basis for agreement on the international control of atomic energy * * *."

The following were regarded as the basic considerations which, even on a technical level, made the U. S. S. R. position untenable:

I. The powers provided for the International Control Commission by the Soviet Union proposals, confined as they are to *periodic inspection* and *special investigations*, are insufficient to guarantee against the diversion of dangerous materials from known atomic facilities, and do not provide the means to detect secret activities.

II. Except by recommendations to the Security Council of the United Nations, the International Control Commission has no powers to enforce either its own decisions or the terms of the convention or conventions on control.

III. The Soviet Union Government insists that the convention establishing a system of control, even so limited as that contained in the Soviet Union proposals, can be concluded only *after* a convention providing for the prohibition of atomic weapons and the destruction of existing atomic weapons has been "signed, ratified, and put into effect." [Italics in original.]

The Commission's work had come to a standstill.

Atomic energy negotiations since 1948

Meeting in Paris in the fall of 1948 the General Assembly, by a vote of 40 to 6, approved the general findings and recommendations of the *First Report* and the specific proposals of part II of the *Second Report* "as constituting the necessary basis for the establishing of an effective system of international control of atomic energy." However, it called upon the UNAEC to continue its work and to study such subjects as it deemed "practicable and useful," and asked that the permanent members of the Commission "consult in order to determine if there exists a basis for agreement * * *." The permanent members were requested to transmit the results of their consultations to the General Assembly.

In the meanwhile, the Soviet Union had served notice of what appeared to be a significant change in its position. In a draft resolution dated September 25, 1948, the Soviets proposed—

To elaborate draft conventions for the banning of atomic weapons and conventions for the establishment of international effective control over atomic energy, taking into account that the convention for the banning of atomic weapons and the convention for the establishment of international control over atomic energy must be signed and implemented and entered into force *simultaneously*.

It was the last word of this resolution that marked a change in the U. S. S. R. stand. Previously, the Soviets had demanded that atomic weapons production be prohibited and stock piles be destroyed *before* a control plan was discussed.

Nonetheless, the new Soviet proposal gave no indication that the Soviets would accede to what the majority regard as an *effective* control plan. Furthermore, the proposal for simultaneous prohibition and control was considered to be physically impossible to implement. "The development of atomic energy is the world's newest industry, and already is one of the most complicated. It would not be reasonable to assume that any effective system of control could be introduced and enforced overnight. Control and prohibition must, therefore, go into effect over a period of time and by a series of stages."

The record of negotiations from the fall of 1948 to the present is largely one of inaction.

On September 23, 1949, President Truman announced that an atomic explosion had occurred in the Soviet Union. One month later, the sponsoring powers of the UNAEC revealed that the consultations between them "had not yet succeeded in bringing about agreement between the U. S. S. R. and the other five powers."

Despite this, the General Assembly, on November 23, 1949, asked that the permanent members of the Commission continue their consultations and keep the Commission and the General Assembly informed of their work. On the same day, Vishinsky revealed that the Soviets no longer entertained favorably the principle of quotas.

On January 19, 1950, consultations came to an end when the Soviet Union withdrew from the discussions over the question of recognition of the Chinese Government.

THE ATOMIC IMPASSE

Regarded in fundamental terms, the deadlock in international control negotiations reflects diametrically opposed notions of the responsibilities of individual nations in a world of atomic energy.

All nations except the Soviet Union and her satellites "put world security first, and are prepared to accept innovations in traditional concepts of international cooperation, national sovereignty, and economic organization where these are necessary for security. The government of the U. S. S. R. puts its sovereignty first and is unwilling to accept measures which may impinge upon or interfere with its rigid exercise of unimpeded state sovereignty."

This basic variance in the objectives of the Soviet Union and the other members of the United Nations is mirrored in the majority and minority control proposals.

The specific differences in the two plans may be summarized as follows:

International Inspection

United Nations.—Complete and continuing inspection by international personnel, including aerial and ground surveys, and inspection of atomic facilities.

Soviet Union.—Periodic inspection of declared plants. Special investigations when there exist "grounds for suspicion"—not that the control agreement has been violated—but that the convention outlawing atomic weapons has been violated. (This could mean that only if a nation were subjected to surprise atomic attack would the necessary "grounds for suspicion" enter into existence.)

International ownership and management

United Nations.—International ownership or management of dangerous facilities and international ownership of source materials and their fissionable derivatives—in order to prevent diversion of such material from existing plants.

Soviet Union.—Complete opposition to international ownership or management provisions.

Strategic balance (quotas)

United Nations.—National quotas to be incorporated into international control treaty.

Soviet Union.—Sees in quotas an instrument for "American domination."

Sanctions

United Nations.—No veto to protect those who violate stipulated provisions of international agreement.

Soviet Union.—All decisions require unanimous consent of permanent members of Security Council.

The permanent members of the UNAEC have summarized the differences between the Soviet plan and the world plan in the following fashion:

"The Soviet Union proposes that nations should continue to own explosive atomic materials.

"The other five Powers feel that under such conditions there would be no effective protection against the sudden use of these materials as atomic weapons.

"The Soviet Union proposes that nations continue, as at present, to own, operate, and manage facilities making or using dangerous quantities of such materials.

"The other five Powers believe that, under such conditions, it would be impossible to detect or prevent the diversion of such materials for use in atomic weapons.

"The Soviet Union proposes a system of control depending on periodic inspection of facilities the existence of which the national government concerned reports to the international agency, supplemented by special investigations on suspicion of treaty violations.

"The other five Powers believe that periodic inspection would not prevent the diversion of dangerous materials and that the special investigations envisaged would be wholly insufficient to prevent clandestine activities."

APPENDIX

Statement by President Truman, January 31, 1950:

It is part of my responsibility as Commander in Chief of the armed forces to see to it that our country is able to defend itself against any possible aggressor. Accordingly, I have directed the Atomic Energy Commission to continue its work on all forms of atomic weapons, including the so-called hydrogen or superbomb. Like all other work in the field of atomic weapons, it is being and will be carried forward on a basis consistent with the over-all objectives of our program for peace and security.

This we shall continue to do until a satisfactory plan for international control of atomic energy is achieved. We shall also continue to examine all those factors that affect our program for peace and this country's security.

Extract from address by Senator Brien McMahon to the United States Senate, February 2, 1950:

The scientists feel more confident that this most horrible of armaments can be developed successfully than they felt in 1940 when the original atomic bomb was under consideration. The hydrogen development will be cheaper than its uranium forerunner. Theoretically, it is without limit in destructive capacity. A weapon made of such material would destroy any military or other target, including the largest city on earth.

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*Chapter of Die Geschichte der Atombombe (Vienna, 1946) by Dr. Hans Thirring, reprinted in the March 1950 Bulletin of the Atomic Scientists:

It is natural to think of the possibility of using fissionable materials, such as U–235 or plutonium, which are difficult to prepare and will never be available in large quantities, as detonators to start other nuclear processes in more abundant materials.

Ever since Cockcroft and Walton succeeded in producing nuclear transformations by fast ions, scientists have been measuring minimum energies required to initiate various nuclear processes. In the earliest experiments on the disintegration of nuclei, the ammunition used were alpha particles with an energy of several million electron volts. Experiments with electrical atom-smashing machines, first employed by Cockcroft and Walton, have revealed that protons with an energy of only a few hundred thousand electron volts were sufficient to initiate certain nuclear processes. Furthermore, it is clear that the initiation of nuclear processes by collisions depends only on the mass and energy of the colliding particles, and not on the way in which the energy was communicated to them. If, therefore, it should be possible to create somewhere in a mass of matter, a temperature high enough for the thermal energy of the atoms to become equal to, or greater than, the energy required for the initiation of a certain nuclear process, it must be possible, at least in principle, to initiate this process in a purely thermal manner, by a kind of "ignition" mechanism.

If, furthermore, the process, started in this way, should proceed so fast and develop so much energy that the temperature should continue to rise, a thermal "chain reaction" would become possible, with the nuclear transformation spreading like an explosion over the whole available amount of the material.

*NOTE.—All of the material from here onward in this appendix is reprinted for purposes of illustrating the kind of technical and semi-technical commentary that has appeared in the public press. No responsibility is assumed for the accuracy or authenticity of such material.

The difficulty of this idea, which appears so simple, lies in the fact that all temperatures that could be reached under the previously available terrestrial conditions were many orders of magnitude smaller than the lowest known threshold of energy required for initiation of a nuclear reaction. In order to raise the average kinetic energy of a gas molecule to a value as low as one electron volt, it would be necessary to heat the gas to a temperature as high as 7,700 degrees on the absolute scale, a temperature higher than that of the surface of the sun. An average energy of one million electron volts could be reached only at a temperature of 7.7 billion degrees.

Before the discovery of nuclear fission and of the nuclear chain reaction, no one could envisage the possibility of creating such temperatures. A detonating atomic bomb creates, however, extreme conditions. In the moment of the explosion, billions and billions of atoms of fission products are created, which fly apart with energies of the order of 100 million electron volts. If these fission nuclei strike other atomic nuclei on their path—for example, the nuclei of a tamper material—they might be able to enter into nuclear reaction with them or to transfer so much energy to the collision partners that these themselves become projectiles of high energy, able in their turn, to produce nuclear reactions. Let us consider a concrete example:

PRINCIPLE OF THE *DD*-REACTION

We assume that the detonator is plutonium in an atomic bomb, and that it is surrounded by a substance which contains deuterium, such as heavy water or heavy paraffin. Outside this first sheath we can imagine the presence of a second one, made of heavy material which acts as a tamper to prevent the bomb from flying apart too soon. In the moment of explosion the plutonium will emit fission products with energies of the order of 100 million electron volts. These will undergo collisions with the deuterons in heavy water and transmit part of their energy to the latter. The energy acquired in this way by the deuterons is, it is true, only a small fraction (not more than 4 percent) of the energy of the original fission products. Nevertheless, this energy may be high enough to permit the accelerated deuteron to undergo a so-called *dd*-reaction with another deuteron, which it might encounter on its path. This reaction will convert two deuterons, each with mass 2 and atomic number 1, into a helium isotope (helium 3) with mass 3 and atomic number 2, and a neutron with mass 1 and atomic number 0. Measurements made in America have established that for this reaction to occur, the collision energy need not be higher than 1/10 mega electron volt (one megavolt is a million volt). The energy released in this reaction, which must appear as the kinetic energy of the two products—the neutron and the helium nucleus—is as high as 3.3 million electron volts. It is true that the fact alone that the energy liberated in this process is considerably higher than the energy required for its initiation, is by no means sufficient to conclude that this process, once initiated, will develop spontaneously into a chain reaction. The fast neutron formed in the *dd*-reaction will have to hit another deuteron under a specially favorable angle to transmit to the latter enough energy to allow it to undergo, in its turn, a *dd*-reaction by collision with still another deuteron, thus continuing the chain. Considering the low probability of nuclear hits, it is obvious that a sequence of two favorable hits will be very unlikely. Therefore, at all temperatures of less than several million degrees, a reaction of the considered type will practically never repeat itself in a chain. In other words, no *dd*-chain reaction is possible under presently known conditions, and this is good because otherwise our earth would probably long ago have vanished in a cloud of incandescent dust, to appear as a new star in the sky.

THEORY OF THE PLUTONIUM-DEUTERON BOMB

The *dd*-reaction will thus never develop on a large scale as the consequence of a single initial process, as is the case in the fission of U–235 or plutonium. However, if heavy water is placed in direct contact with detonating plutonium, what will occur, is not a single elementary reaction, but a simultaneous impact on deuterium atoms of billions of high-energy fission products, creating such enormous temperatures that a considerable fraction of deuterons will acquire the energy sufficient to undergo a *dd*-reaction. The occurrence of a large number of these secondary reactions will cause a further increase in temperature, and it is not altogether impossible, that a chain reaction will maintain itself through a purely thermal mechanism despite the enormously high temperature required. Under the pressures and temperatures existing in the interior of stars, thermal nuclear reactions are actually known to occur. It is, however, open to grave doubts whether, by the use of an amount of tamper material which will keep the bomb within reasonable dimensions, the plutonium-deuteron bomb could be prevented from flying apart much too fast to maintain the temperature required for the continuation of the thermal chain reaction. For this reason, the possibility of producing chain reactions of light elements is still open to grave question.

THE LITHIUM HYDRIDE BOMB

Another substance which perhaps could be brought to chain reaction by the detonating action of an atomic bomb, is a mixture containing lithium and hydrogen, for example, the compound lithium hydride. At a temperature of several million degrees, the lithium nuclei (mass 7, atomic number 3) can react with hydrogen nuclei (mass 1, atomic number 1) forming two nuclei of ordinary helium (mass 4, atomic number 2). The impact of a high energy proton on a lithium nucleus will produce an intermediate nucleus of mass 8 and charge 4, which will fission into two alpha particles (helium nuclei) of very high energy. American measurements have shown that here, too, the initiation of the nuclear reaction is possible with energies of less than 1/10 mega electron volt, while the energy liberated in the reaction has the remarkably high value, for such light nuclei, of 17.3 million electron volts!

Table 1 shows the calculation of the total energy which will be liberated by complete fission of one kilogram of U–235, compared to the energy liberated from an equal mass of deuterium undergoing a *dd*-process, and an equal mass of lithium and hydrogen undergoing transformation into helium.

TABLE 1.—*Approximate calculation of the energy which can be obtained through nuclear transformation of 1 kilogram*

Substance	U–235	D_20	LiH
Process	Fission	${}^2_1H(d,n){}^3_2He$	${}^7_3Li(p,\alpha){}^4_2He$
Energy per single atom.	200 MeV	3.3 MeV	17.3 MeV
Atomic weight	235	$2\times2+16=20$	$7+1=8$
No. of atoms in 1 kilogram.	$\frac{1,000}{235\times1.67\times10^{-24}}=$ $=2.55\times10^{24}$	$\frac{1,000}{20\times1.67\times10^{-24}}=$ $=30\times10^{24}$	$\frac{1,000}{8\times1.67\times10^{-24}}=$ $=75\times10^{24}$
Energy per 1 kilogram.	$2.55\times10^{24}\times200$ MeV= $=5.1\times10^{26}$ MeV= $=5.1\times10^{26}\times1.6\times10^{-6}=$ $=8.16\times10^{20}$ erg $=8.16\times10^{20}\times2.39\times10^{-11}=$ $=1.95\times10^{10}$ kcal $=1.95\times10^{10}/860=$ $=22,700,000$ kWh	$3\times10^{25}\times3.3$ MeV $=10^{26}$ MeV $=1.6\times10^{20}$ erg $=0.38\times10^{10}$ kcal $=4,400,000$ kWh	$7.5\times10^{25}\times17.3$ MeV= $=1.3\times10^{27}$ MeV $=21\times10^{20}$ erg $=5\times10^{10}$ kcal $=58,000,000$ kWh

1 MeV=1.6×10^{-6} erg 1 erg=2.39×10^{-11} kcal 1 kcal=1/860 kWh

As one can see from the table, one kilogram of lithium and hydrogen will produce almost three times as much energy as an equal mass of U–235. Remember that lithium is not a rare element, and that one could easily obtain as many *tons* of it, for use in a superbomb, as are now available *kilograms* of plutonium for use in "ordinary" atomic bombs. The total energy of available nuclear explosives could thus be increased several thousand times compared to the energy that now can be stored in the form of plutonium and U–235 alone. God protect the country over which a six-ton bomb of lithium hydride will ever explode.

If this idea is at all capable of realization, it is obvious that a uranium 235, or a plutonium bomb of the present type will have to serve as a detonator in the new superbomb. In contrast to the conventional detonator used to explode shells, this detonator cannot be made as small as may be desirable, because it has to fulfill the critical size condition required for the development of a fission chain reaction. Thus, if the rare materials, U–235 or plutonium are used successfully as detonating caps for superbombs, it would not be possible to make thousands of such bombs from a single kilogram of fissionable materials. The "progress" achieved by the realization of the superbomb (if you can call it progress) will therefore consist in considerable increase in the *power* of each single atomic bomb, not in a substantial increase of their *number*.

Extract from The Hydrogen Bomb, an article by Dr. Louis N. Ridenour appearing in the March 1950, Scientific American:

In the President's first announcement of the Hiroshima atomic bomb, it was stated that the bomb drew its energy from the same source that fuels the sun and the stars. This statement is true only in the loosest sense. To be sure, a uranium-fission bomb, like the sun, derives energy from the transformation of one atomic species into others, but the types of reaction involved in the two cases are quite different.

As Robert E. Marshak explained in the January 1950, issue of this magazine, there is excellent reason to believe that the energy source of most stars, including the sun, is a rather complicated chain of nuclear transformations whose end result is to form one atom of helium out of four atoms of hydrogen. An atom of carbon, which plays an intermediate role in this chain of reactions, is finally recovered unchanged, and is thus available to participate once more in the stellar energy cycle. In the sun and the stars, then, the source of energy is a chain of so-called thermonuclear reactions that ends in fusing four light hydrogen nuclei into the heavier and more complicated helium nucleus. The old-fashioned atomic bomb, on the other hand, uses as its explosive the nuclei of some of the heaviest elements known to man: uranium and plutonium. Energy is released when one of these heavy nuclei splits, or fissions, into two lighter, simpler nuclei. Thus the lightest atoms liberate energy if they are combined into heavier atoms; the heaviest atoms liberate energy when they are split into lighter ones. Only near the middle of the periodic table of the chemical elements do we find atomic species that are fully stable, in the sense that energy cannot be liberated either by combining them into heavier atoms or by splitting them into lighter ones.

To paraphrase a remark of the physicist George Gamow, we live in the midst of an atomic powder magazine, where immense amounts of energy are locked in every bit of matter. Why, then, are we safe? Why does common matter, possessed as it is of tremendous stores of energy, seem so inert, so permanent? The answer is that in order to liberate the energy of a fusion or a fission reaction we must ourselves invest some energy, just as we must expend energy to strike a match.

In the case of nuclear fission, the energy investment is small. Fission occurs when an atom of uranium 235, plutonium 239, or uranium 233 captures a neutron, even one of very slow speed. But these neutrons must be somehow produced, since they do not occur free in nature, and are in fact unstable. The nuclear "chain reaction" that is exploited in atomic bombs and in nuclear reactors like those at Hanford is possible only because the fission reaction itself releases neutrons, the very particles that are needed to keep it going.

If the lump of uranium or plutonium in which these neutrons are liberated is large enough, the neutrons released by one fission process will cause other fissions before they escape from the lump, and the process will go on faster and faster until an atomic explosion has been produced. The lump of uranium is then said to have exceeded the "critical size."

This limitation on critical size dictates the design of fission bombs. Detonation of such a bomb requires the rapid assembly of an overcritical mass; as soon as this is assembled, it blows up in about half a millionth of a second. The greatest ingenuity is needed to achieve an instantaneous condition exceeding the critical by as much as a few per cent; no amount of ingenuity has yet allowed the design of an efficient fission bomb so much as two or three times critical size. Thus there are inherently narrow limits to the size of a fission bomb: as it begins to exceed the critical, it explodes at once; if it is smaller, it cannot be exploded at all.

At the opposite end of the scale, among the light elements, the explosive conversion of mass into energy is not so easily achieved in terrestrial laboratories. To cause two light atoms to fuse into a heavier one, we must overcome powerful forces of electrical repulsion, since each nucleus is positively charged. Up to now this has been accomplished by scientists only laboriously, with poor efficiency and on an extremely small scale, by striking target atoms with a fast-moving beam of atoms accelerated in an electronuclear machine, or "atom-smasher." Only at energies of hundreds of thousands or millions of volts do collisions between most types of light atoms produce fusion reactions with substantial likelihood.

In the centers of the stars fusion reactions go on all the time, because the temperature there is some 20 million degrees Centigrade. The average energy of an atom at this temperature is only some 1,700 electron volts, but some atoms have several times this energy, and collisions between atomic nuclei are so frequent that fusion reactions are produced in substantial numbers. We cannot maintain stellar temperatures on the earth, but we can produce them for very small fractions of a second. In the explosion of a uranium or plutonium bomb, the central temperature of the exploding mass has been estimated as high as 50 million degrees C. At such a temperature fusion reactions in a dense mass of light atoms occur often enough to liberate significant amounts of energy.

Obviously the fusion reactions that are likely to be most effective for producing energy are those that will go best at relatively low collision energies, since even the highest temperatures reached in the explosion of an atomic bomb correspond to rather modest bombarding energies from the laboratory standpoint. For this reason, the stellar-energy reaction cycle is out of the question; this cycle involves the fusion of hydrogen with heavy atoms such as carbon and nitrogen, and therefore proceeds relatively slowly even at temperatures of millions of degrees. It has been known for some time, however, that fusion reactions between the rarer, heavier isotopes of hydrogen can take place much more rapidly at substantially lower temperatures.

A few years ago the reaction that would have been chosen as the most promising for a hydrogen bomb was the fusion of two atoms of deuterium, or hydrogen of mass 2, containing one proton and one neutron. This results in the formation of helium 3, with the emission of a neutron and the release of about four million electron volts of energy. Gamow has calculated the thermonuclear energy release from this reaction; the results were given in his 1946 book *Atomic Energy*. He remarked that if the reaction took place at a temperature of something over one million degrees C., "a small charge of deuterium could be used as an explosive with tremendous destructive power."

Nowadays we know that a more effective reaction can be obtained with hydrogen 3, known as tritium, a radioactive but long-lived isotope of hydrogen that has one proton and two neutrons in its nucleus. Tritium not only reacts faster than deuterium at low temperatures, but also liberates more energy when it does so. A fusion reaction of tritium with deuterium produces helium 4, with the emission of a neutron; its energy yield is 17.6 million electron volts. Tritium can also fuse with tritium, yielding helium 4, two neutrons and 11.4 million electron volts of energy; the cross section for this reaction is not available in the published literature, but it is probably large.

Ponderable amounts of tritium have been and are being made by the Atomic Energy Commission in its huge facilities. The designer of a fusion bomb clearly would start with a fission bomb of uranium or plutonium, the explosion of which would produce the high temperatures required for the thermonuclear fusion reaction. To the fission bomb he would add a certain mixture of deuterium and tritium to fuel the fusion process. The final energy release of the bomb—its total deadliness—would be determined by the amount of deuterium added. To say that the fusion bomb would be 2, 7, 10, 100 or 1,000 times as devastating as the conventional fission bomb is to speak from ignorance; the effective size of a fusion bomb will depend upon the intentions and the skill of its designers.

Note, however, that there is here no concept like that of critical size. The size of the bomb depends, and depends exactly, on the amount of the reacting elements built into it. The fission detonator itself must be made overcritical in order to explode, but the happenings thereafter will depend on the amount of fuel provided for the fusion reaction.

Here, then, are the technical conclusions that one must draw about the fusion bomb:

First, it can be made.

Second, there is no limit, in principle, to the size of a fusion bomb. It cannot be smaller than a fission bomb, since it must use a fission bomb as detonator, but it can be many times, perhaps thousands of times, bigger.

Third, while fission can be controlled in an orderly way to produce useful power in a reactor, the fusion reaction offers no prospect at the present time of any use except in terms of an explosion. We cannot find in the development of the fusion bomb any such peacetime values as are inherent in the development of nuclear fission. Except where the uses of peace demand the detonation of an explosive equivalent to, say, a million tons of TNT, there is no use for a fusion reaction. Thus when we discuss the hydrogen bomb we are clearly speaking of a weapon, and a weapon only.

Fourth, we are speaking of a very special type of weapon—one that is appropriate only to the destruction of large targets. A weapon of this sort is clearly of much greater significance to other nations, such as the U. S. S. R., than it is to us. We have several large targets; the U. S. S. R. has only one or two.

Fifth, the fusion bomb is not a brand new possibility that has suddenly burst upon the minds of men. For example, J. Robert Oppenheimer, wartime director of the bomb laboratory at Los Alamos, wrote cryptically in late 1945 in the book *One World or None:* "In this connection it is clearly relevant to ask what technical developments the future might have in store for the infant atomic-weapon industry. . . . Proposals that appear sound have been investigated in a preliminary way, and it turns out that they would reduce the cost of destruction per square mile probably by a factor of 10 or more, but they would involve a great increase in the unit power of the weapons. Such weapons would clearly be limited in application to the destruction of very major targets, such as greater New York." Oppenheimer was talking of the fusion bomb. Physicists knew it then, of course; we all know it now. And it would be naive indeed to suppose that the U. S. S. R. has not given thought to it on its own account.

Extract from The Hydrogen Bomb, an article by Dr. Hans Bethe appearing in the April, 1950 issue of Scientific American:

Everybody who talks about atomic energy knows Albert Einstein's equation $E=Mc^2$: *viz,* the energy release in a nuclear reaction can be calculated from the decrease in mass. In the fission of the uranium nucleus, one tenth of one per cent of the mass is converted into energy; in the fusion of four hydrogen nuclei to form helium, seven tenths of one per cent is so converted. When these statements are made in newspaper reports, it is usually implied that there ought to be some way in which all the mass of a nucleus could be converted into energy, and that we are merely waiting for technical developments to make this practical. Needless to say, this is wrong. Physics is sufficiently far developed to state that there will never be a way to make a proton or a neutron or any other nucleus simply disappear and convert its entire mass into energy. It is true that there are processes by which various smaller particles—positive and negative electrons and mesons—are annihilated, but all these phenomena involve at least one particle which does not normally occur in nature and therefore must first be created, and this creation process consumes as much energy as is afterwards liberated.

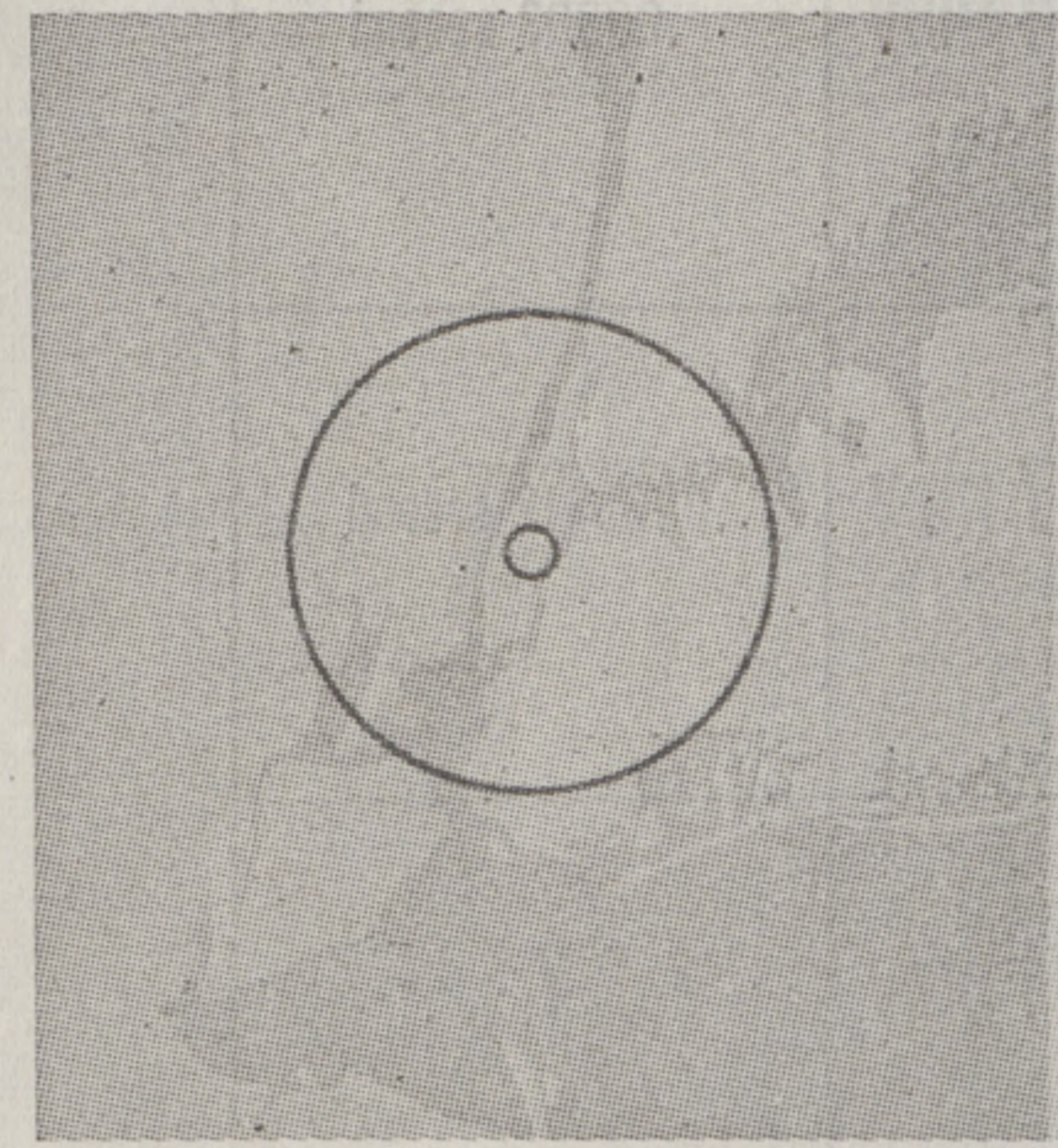
All the nuclear processes from which energy can be obtained involve the rearrangement of protons and neutrons in nuclei, the protons and neutrons themselves remaining intact. Hundreds of experimental investigations through the last 30 years have taught us how much energy can be liberated in each transformation, whether by the fission of heavy nuclei or the fusion of light ones. In the case of fusion, only the combination of the very lightest nuclei can release very large amounts of energy. When four hydrogen nuclei fuse to form helium, .7 percent of the mass is tranformed into energy. But if four helium nuclei were fused into oxygen, the mass would decrease by only .1 percent; and the fusion of two silicon atoms, if it ever could occur, would release less than .02 percent of the mass. Thus there is no prospect of using elements of medium atomic weight for the release of nuclear energy, even in theory.

The main problem in the release of nuclear energy in those cases that we can consider seriously is not the amount of energy released—this is always large enough—but whether there is a mechanism by which the release can take place at a sufficient rate. This consideration is almost invariably ignored by science reporters, who seem to be incurably fascinated by $E=Mc^2$. In fusion the rate of reaction is governed by entirely different factors from those in fission. Fission takes place when a nucleus of uranium or plutonium captures a neutron. Because the neutron has no electric charge and is not repelled by the nucleus, temperature has no important influence on the fission reaction; no matter how slow the neutron, it can enter a uranium nucleus and cause fission. In fusion reactions, on the other hand, two nuclei, both with positive electric charges, must come into contact. To overcome their strong mutual electrical repulsion, the nuclei must move at each other with great speed. Ridenour explained how this is achieved in the laboratory by giving very high velocities to a few nuclei. This method is very inefficient because it is highly unlikely that one of the fast projectiles will hit a target nucleus before it is slowed down by the many collisions with the electrons also present in the atoms of the target. Therefore the energy released by nuclear reactions in these laboratory experiments is always much less than the energy invested in accelerating the particles.

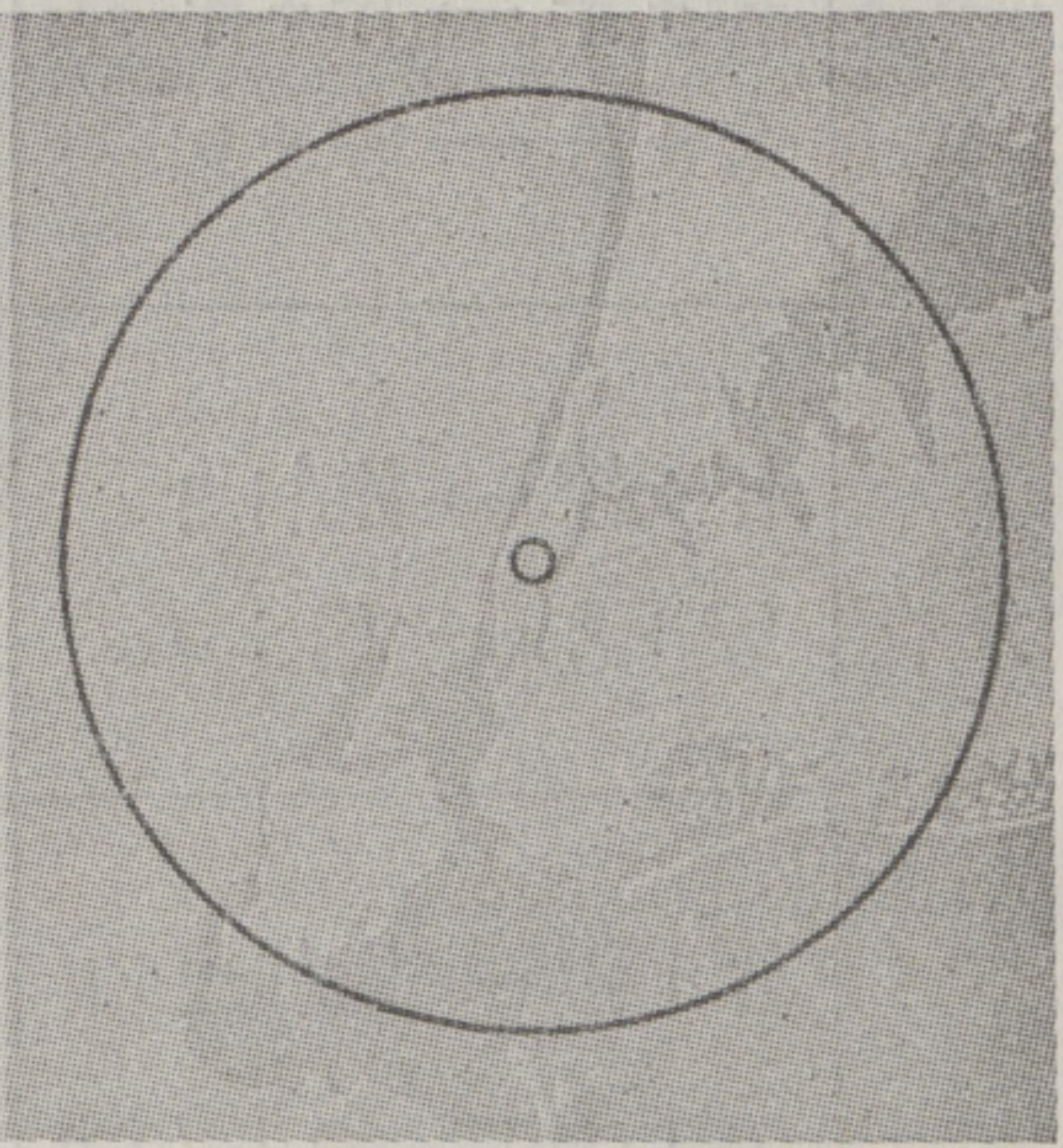
The only known way that energy can be extracted from light nuclei by fusion is by thermonuclear reactions, *i. e.*, those which proceed at exceedingly high temperatures. The prime example of such reactions occurs in the interior of stars, where temperatures are of the order of 20 million degrees Centigrade. At this temperature the average energy of an atom is still only 1,700 electron volts—much less than the energies given to nuclear particles in "atom smashers." But all the particles present—nuclei and electrons—have high kinetic energy, so they are not slowed down by colliding with one another. They will keep their high speeds. Nevertheless, in spite of the high temperature, the nuclear reactions in stars proceed at an extremely slow rate; only one percent of the hydrogen in the sun is transformed into helium in a billion years. Indeed, it would be catastrophic for the star if the reaction went much faster.

The temperature at the center of a star is kept high and very nearly constant by an interplay of a number of physical forces. The radiation produced by nuclear reactions in the interior can escape from the star only with great difficulty. It proceeds to the surface not in a straight line but by a complicated, zigzag route, since it is constantly absorbed by atoms and re-emitted in new directions. It is this slow escape of radiation that maintains the high interior temperature, which in turn maintains the thermonuclear reactions. Only a star large enough to hold its radiations for a long time can produce significant amounts of energy. The sun's radiation, for example, takes about 10,000 years to escape. A star weighing one tenth as much as the sun would produce so little energy that it would not be visible, and the largest planet, Jupiter, is already so small that it could not maintain nuclear reactions at all. This rules out the possibility that the earth's atmosphere, or the ocean, or the earth's crust, could be set "on fire" by a hydrogen superbomb and the earth thus be converted into a star. Because of the small mass of the bomb, it would heat only a small volume of the earth or its atmosphere, and even if nuclear reactions were started, radiation would carry away the nuclear energy much faster than it developed, and the temperature would drop rapidly so that the nuclear reaction would soon stop.

If thermonuclear reactions are to be initiated on earth, one must take into consideration that any nuclear energy released will be carried away rapidly by radiation, so that it will not be possible to keep the temperature high for a long time. Therefore, if the reaction is to proceed at all, it must proceed very quickly. Reaction times of billions of years, like those in the sun, would never lead to an appreciable energy release; we must think rather in terms of millionths of a second. On the other hand, on earth we have a choice of materials: whereas the stellar reactions can use only the elements that happen to be abundant in stars, notably ordinary hydrogen, we can choose any elements we like for our thermonuclear reactions. We shall obviously choose those with the highest reaction rates.



BLAST EFFECT of present and proposed atomic weapons is projected on a map of New York City and the surrounding area. A uranium bomb set off above the SCIENTIFIC AMERICAN office in midtown would cause severe destruction within a radius of a mile (*small circle*); a hydrogen bomb 1,000 times more powerful would cause severe destruction within 10 miles (*large circle*).



FLASH EFFECT of a hydrogen bomb 1,000 times more powerful than present bombs would be relatively greater than its blast effect. The Hiroshima bomb caused fatal burns at distances up to 4,000 to 5,000 feet (*small circle*). A hydrogen bomb would cause fatal burns at distances of 20 miles or more (*large circle*). The inhabitants of Chicago and its suburbs could thus be wiped out.

$H^1 + H^1 \longrightarrow H^2 + e^+$	1.4 mev	100,000,000,000 years
$H^2 + H^1 \longrightarrow He^3 + hv$	5 mev	.5 second
$H^3 + H^1 \longrightarrow He^4 + hv$	20 mev	.05 second
$H^2 + H^2 \longrightarrow He^3 + n$	3.2 mev	.00003 second
$H^2 + H^2 \longrightarrow H^3 + H^1$	4 mev	.00003 second
$H^3 + H^2 \longrightarrow He^4 + n$	17 mev	.0000012 second
$H^3 + H^3 \longrightarrow He^4 + n + n$	11 mev	?

THE NUCLEAR REACTIONS involving the three isotopes of hydrogen, H^1, H^2 (deuterium) and H^3 (tritium) illustrate a fundamental consideration in making a hydrogen bomb. The reactions are at left, the energy released by each is in center, the time required for each is at right. The reactions involving the heavier isotopes of hydrogen proceed at a much faster rate.

The reaction rate depends first of all, and extremely sensitively, on the product of the charges of the reacting nuclei; the smaller this product, the higher the reaction rate. The highest rates will therefore be obtainable from a reaction between two hydrogen nuclei, because hydrogen has the smallest possible charge—one unit. (The principal reactions in stars are between carbon, of charge six, and hydrogen.) We can choose any of the three hydrogen isotopes, of atomic weight one (proton), two (deuteron) or three (triton). These isotopes undergo different types of nuclear reactions, and the reactions occur at different rates.

The fusion of two protons is called the proton-proton reaction. It has long been known that this reaction is exceedingly slow. As Robert E. Marshak stated in his article, "The Energy of Stars," in the January issue of this magazine, the proton-proton reaction takes 100 billion years to occur at the center of the sun. Ridenour pointed out that the situation is quite different for the reactions using only the heavy isotopes of hydrogen: the deuteron and triton. A number of reported measurements by nuclear physicists have shown that the reaction rates for this type of fusion are high.

A further variable governing the rate of the reaction is the density of the material. The more atoms there are per unit volume, the higher the probability for nuclear collisions.

It is also well known, as Ridenour noted, that the reactions would require enormous temperatures. Whether the temperature necessary to heat heavy hydrogen sufficiently to start a thermonuclear reaction can be achieved on the earth is a major problem in the development of the H-bomb. To find a practical way of initiating H-bombs will require much research and considerable time.

What would be the effects of a hydrogen bomb? Ridenour pointed out that its power would be limited only by the amount of heavy hydrogen that could be carried in the bomb. A bomb carried by a submarine, for instance, could be much more powerful than one carried by a plane. Let us assume an H-bomb releasing 1,000 times as much energy as the Hiroshima bomb. The radius of destruction by blast from a bomb increases as the cube root of the increase in the bomb's power. At Hiroshima the radius of severe destruction was one mile. So an H-bomb would cause almost complete destruction of buildings up to a radius of 10 miles. By the blast effect alone a single bomb could obliterate almost all of Greater New York or Moscow or London or any of the largest cities of the world. But this is not all; we must also consider the heat effects. About 30 percent of the casualties in Hiroshima were caused by flash burns due to the intense burst of heat radiation from the bomb. Fatal burns were frequent up to distances of 4,000 to 5,000 feet. The radius of heat radiation increases with power at a higher rate than that of blast, namely by the square root of the power instead of the cube root. Thus the H-bomb would widen the range of fatal heat by a factor of 30; it would burn people to death over a radius of up to 20 miles or more. It is too easy to put down or read numbers without understanding them; one must visualize what it would mean if, for instance, Chicago with all its suburbs and most of their inhabitants were wiped out in a single flash.

In addition to blast and heat radiation there are nuclear radiations. Some of these are instantaneous; they are emitted by the exploding bomb itself and may be absorbed by the bodies of persons in the bombed area. Others are delayed; these come from the radioactive nuclei formed as a consequence of the nuclear explosion, and they may be confined to the explosion area or widely dispersed. The bombs, both A and H, emit gamma rays and neutrons while they explode. Either of these radiations can enter the body and cause death or radiation sickness. It is likely, however, that most of the people who would get a lethal dose of radiation from the H-bomb would be killed in any case by flash burn or by collapsing or burning buildings.

There would also be persistent radioactivity. This is of two kinds: the fission products formed in the bomb itself, and the radioactive atoms formed in the environment by the neutrons emitted from the bomb. Since the H-bomb must be triggered by an A-bomb, it will produce at least as many fission products as an A-bomb alone. The neutrons produced by the fusion reactions may greatly increase the radioactive effect. They would be absorbed by the bomb case, by rocks and other material on the ground, and by the air. The bomb case could be so designed that it would become highly radioactive when disintegrated by the explosion. These radioactive atoms would then be carried by the wind over a large area of the bombed country. The radioactive nuclei formed on the ground would contaminate the center of the bombed area for some time, but probably not for very long because the constituents of soil and buildings do not form many long-lived radioactive nuclei by neutron capture.

Neutrons released in the air are finally captured by nitrogen nuclei, which are thereby transformed into radioactive carbon 14. This isotope, however, has a long half-life—5,000 years—and therefore its radioactivity is relatively weak. Consequently even if many bombs were exploded, it is not likely that the carbon 14 would become dangerous.

Extract from speech of Dr. Robert F. Bacher, California Institute of Technology, at Town Hall, Los Angeles, March 27, 1950:

It has been known for a great many years that if one could somehow find a way of putting light atomic nuclei together to make heavier nuclei, it would be possible to extract energy. It has also been known for a long time that if one could take the heaviest nuclei and split them apart one would be able to obtain energy.

The first indication that either of these processes might be important to us as a source of energy came from the suggestion by Hans Bethe that the fusion of the light elements was our fundamental source of energy in the sun and stars. Dr. Bethe worked his ideas out in some detail and scientists now believe that this is the origin of solar energy. These ideas were well developed before the fission of uranium was discovered. The discovery of the fission of uranium in 1938 was immediately recognized as a possible source of energy for man. Released gradually he could use this energy for power. Released suddenly this energy could provide an explosion.

Two fundamental scientific discoveries which followed soon after the discovery of fission were of far-reaching importance. The first of these was that in the fission of uranium caused by the absorption of low energy neutrons, additional neutrons were released in the process. The importance of this fact is that the fission of uranium could produce neutrons which could then produce another fission, hence the term chain reaction. These neutrons released in fission could make the reaction self-perpetuating.

The second discovery was that some of these neutrons were emitted some time after the fission took place. It was this fact that made the controlled chain reaction or nuclear reactor a possibility. Without these delayed neutrons we would have no way of controlling a nuclear reactor.

With the fusion of the light elements the situation is entirely different. Here the basic nuclear reactions which lead to the release of relatively large quantities of energy are those which occur when the nuclear particles collide at high velocity or high relative kinetic energy. At the center of the stars the temperature is many millions of degrees Centigrade and the particles of matter are moving at such high speeds that these nuclear reactions may take place. Even then, only a few nuclear reactions are possible. There is no possibility that the energy release from this type of reaction can be controlled on the earth. In the stars the reaction is controlled because of their great size. On the earth these self-sustaining thermonuclear reactions will either give an explosion or nothing at all.

Whether or not a hydrogen bomb can be made depends upon whether it is possible to create on earth, an assembly of materials which will produce a nuclear reaction if heated to a sufficiently high temperature and then to devise a way to raise these materials to that temperature.

The temperature required is comparable to that reached in the interior of the sun which is more than 10,000,000° C. The only way that we know to reach such a temperature today is in an atomic bomb where the sudden release of energy causes the materials of the bomb to be heated to an extremely high temperature.

The main light element, of course, to which I have been referring is hydrogen. Now ordinary hydrogen just won't work. The scientific evidence for this seems to be quite clear. But hydrogen as it is found in nature has two forms or isotopes. The heavy hydrogen discovered by Urey nearly 20 years ago, is a possibility. In recent years heavy hydrogen, as contained in water, has been separated in relatively large quantities.

There is another possibility. For more than 15 years it has been known that another isotope of hydrogen called tritium because it has mass three, is produced in nuclear reactions. This material is radioactive and ordinarily does not exist in nature. It has a half life of 12 years but its nuclear properties are such that it is of basic interest in the release of energy by fusion.

It has been known for many years that tritium could be produced in a nuclear reaction in which neutrons are absorbed. As you all know the big nuclear reactors which are now in operation do produce neutrons in large quantity. These neutrons are ordinarily used in the production of plutonium. But they could be used just as well to produce quantities of tritium. Any nuclear physicist can sit down and figure out the theoretical limit of the amount of tritium that can be produced with a given number of neutrons. He would quickly recognize that since you need neutrons to produce plutonium and neutrons to produce tritium, a nuclear reactor could be used to produce one or the other at will. It would be necessary, of course, to know a great deal about the actual workings of a nuclear reactor in order to say just how much tritium could be produced in that reactor if one were willing to forego the production of a certain amount of plutonium. It sounds as if the production of tritium in quantity is at least a fairly expensive if not formidable process.

That these two isotopes of hydrogen can possibly play a fundamental role in the release of nuclear energy by fusion is well known. Just exactly what relative role they play and how they might play it, is not a subject for open discussion today. These questions are secret and we can have no discussion of them. But any nuclear physicist will quickly grasp the basic science requirements even though the bomb technology is much more complicated.

The real problem in developing and constructing a hydrogen bomb is: "How do you get it going?" The heavy hydrogens, deuterium and tritium, are suitable substances if somehow they could be heated hot enough and kept hot. This problem is a little bit like the job of making a fire at 20° below zero in the mountains with green wood which is covered with ice and with very little kindling. Today, scientists tell us that such a fire can probably be kindled.

Once you get the fire going, of course, you can pile on the wood and make a very sizable conflagration. In the same way with the hydrogen bomb, more heavy hydrogen can be used and a bigger explosion obtained. It has been called an open-ended weapon, meaning that more materials can be added and a bigger explosion obtained.

Let us look for a moment at what sort of an explosion is imagined. Here I shall take the figures which have been commonly reported in the press and stick to round numbers. I believe that these are quite adequate for you to obtain some general idea of what such an explosion is like.

In 1945 President Truman stated that the atomic bomb was equivalent to 20,000 tons of TNT. In talking about the hydrogen bomb it has commonly been speculated that such a bomb would be 1,000 times as powerful as the bomb dropped on Hiroshima. If it is 1,000 times as powerful this would mean that it would have an explosive effect equivalent to about 20,000,000 tons of TNT.

Now it happens that the radius of damage from a big explosion increases as the cube root of the energy is released. With a bomb a thousand times more powerful than the Hiroshima bomb the radius of damage will be 10 times greater. Since the radius for almost complete destruction from blast was approximately 1 mile at Hiroshima, the corresponding radius for a hydrogen bomb 1,000 times as large would be approximately 10 miles.

Such a hydrogen bomb would be sufficiently great to cause almost complete destruction of any metropolitan area known today. In Los Angeles, for example, a circle of 10 miles' radius would cover most but not all of the metropolitan area. Outlying communities would not be included but would still suffer damage.

There are other damage effects from atomic weapons. At Hiroshima people who were in the open and exposed directly to the light of the bomb were seriously burned. With a hydrogen bomb these effects will be much greater and may extend to an even greater radius than the blast effects. On the other hand, the radiation which produces these burns is very easily absorbed. It is very much like the radiation from the sun and a shadow or a blanket of smog is a great protection. The same evil-smelling smog blanket which cuts off our sun may, after all, be some protection.

Generally speaking, one would expect the flash burn effects to increase as the square root of the power of the bomb. In other words, for a bomb a thousand times greater than Hiroshima the effects would be expected to extend roughly 30 times as far. At Hiroshima flash burns were severe out to two-thirds of a mile and without smog absorption or shadows, similar burns might be expected out to 20 miles for a hydrogen bomb. Except for a hydrogen bomb exploded at extraordinarily high altitude, such a damage radius would mean that shadows of buildings, trees, bushes, and other objects would be very important in cutting down the direct effect of flash burn. If you couldn't see the bomb directly you would expect no effect of flash burn. For a bomb exploded at an elevation of 2 miles it would be rather like trying to see Mount Baldy from 20 miles away. Even without atmospheric absorption there would be relatively few spots where some building or other structure would not be in the way.

Atomic bombs, and hydrogen bombs as well, may be expected to release neutrons and penetrating gamma radiation. These particles and rays, however, are absorbed fairly easily in air and will not have an appreciably greater radius of action for a hydrogen bomb than for an ordinary atomic bomb. People who are sufficiently close to be killed by penetrating radiation would very likely be killed by blast effects, either direct or indirect, in any event. Among those injured, some will definitely show effects of radiation damage.

There has been a great deal of speculation about the radioactive products produced by a hydrogen bomb. The disintegration products produced in the explosion are themselves not radioactive as are the fission products from an atomic bomb. But since an atomic bomb would be needed in order to get the conflagration going, some fission products from that bomb would doubtless be present. But large quantities of radioactivity may be produced from the neutrons which are released in the nuclear conflagration.

If the neutrons released in the hydrogen bomb explosion are absorbed in some material which becomes artificially radioactive, then a very large quantity of this radioactive material will be produced in a big explosion. On the other hand, many of these neutrons might be absorbed in material which would be inactive and the effects of the radioactivity at least in part avoided. If the neutrons escaped into the air, many of them would be absorbed by nitrogen and, by a nuclear reaction, produce radioactive carbon. This material is most disagreeable as a radioactive contaminant since it has a half-life of many thousands of years.

If such a bomb were exploded under water, however, very few of the neutrons would escape and most of them would be used to produce radioactive sodium or to activate other elements in sea water, or to produce heavy hydrogen by neutron capture in ordinary hydrogen.

The radioactivity effects of a hydrogen bomb are thus difficult to estimate, since they depend very much on where the bomb is exploded and what material surrounds it. Under conditions in which the largest amount of radioactivity is formed it would be a dangerous hazard. One of the real scare stories about the effects of radioactivity, has postulated the complete explosion of 500 tons of deuterium, which, while not impossible as far as anyone can say, is stretching probabilities a long way.

From our brief analysis of well-known scientific information it appears that a hydrogen bomb would require a considerable quantity of heavy hydrogen, both deuterium and tritium perhaps, as well as an atomic bomb to set it off and raise the temperature sufficiently so that a nuclear conflagration can exist. Technically the problem is to figure out how a sizable fraction of the energy of the heavy hydrogen can be released before the material is cooled too much by emitted radiation or dispersed by the explosion. In the stars the radiation is retained because the stellar atmosphere is relatively opaque and there is an enormous temperature difference between the center and the outside of the star. In a hydrogen bomb there is no such protective layer and the central problem is to get a large fraction of the energy released while the temperature is still high enough.

Whether this can be done will, of course, not be certain until it has been done. There are many opinions as to how difficult it may be. Since the President has directed the Atomic Energy Commission to continue with the development, we can assume that this development is regarded as both possible and feasible.

So much for the technical problems which must be solved in order to develop a hydrogen bomb. While it seems possible that these problems may be solved, whether or not a hydrogen bomb can be developed will be fully determined only when a bomb has been made and exploded.

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Draft Resolutions AEC/36 and AEC/37 submitted for the Commission's consideration by delegation of the United States and delegation of the U. S. S. R., respectively.

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Security Council. Draft resolution submitted by the Representative of the Union of Soviet Socialist Republics concerning prohibition of the atomic weapon and reduction by one-third of the armaments and armed forces of the permanent members of the Security Council, at the 407th meeting of the Security Council on February 8, 1949. Lake Success, Document S/1246, February 8, 1949. 3 p. mimeo.

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Austin, Warren R. Atomic energy: a specific problem of the United Nations. U. S. DEPARTMENT OF STATE BULLETIN (Washington) October 10, 1949, v. 21: p. 543–544.

Address made before the American Association for the United Nations on September 29, 1949, which contains an analysis of the plan proposed last fall by the U. N. Atomic Energy Commission and the counter-proposals made by the U. S. S. R.

Austin, Warren R. U. S.-U. K. "Essentials of peace"—A challenge to Soviet sincerity. DEPARTMENT OF STATE BULLETIN (Washington) November 28, 1949, v. 21: p. 801–808.

Denounces Russian position on atomic control.

Comparison of atomic energy legislation of the United States and certain foreign countries. A factual study of the provisions contained in the laws of certain foreign countries and a résumé of decrees, ordinances, and executive orders of certain countries not having a complete atomic energy act. December 21, 1948. Washington, U. S. Govt. print. off., 1948. 35 p. (80th Cong., 2d Sess. Joint Committee Print.)

Limited distribution by the Joint Congressional Committee on Atomic Energy, Room 4A, The Capitol, Washington, D. C.

First Report of the United Nations Atomic Energy Commission to the Security Council, December 31, 1946 (Department of State publication 2737).

The international control of atomic energy, growth of a policy. An informal summary record of the official declarations and proposals relating to the international control of atomic energy made between August 6, 1945 and October 15, 1946. Department of State, Washington, pp. 281, publication 2702 (1946).

The international control of atomic energy, policy at the crossroads. An informal summary record of the policy developments concerning the international control of atomic energy, October 15, 1946 to May 17, 1948. Department of State, Washington, p. 251, publication 3161 (1948).

Making democracy work and defending it from its enemies. Address by the President. DEPARTMENT OF STATE BULLETIN (Washington) March 6, 1950, v. 22: p. 347–350.

In an address delivered at the George Washington National Masonic Memorial at Alexandria, Va., on February 22, 1950, the President restated his belief in the need for an effective plan for international control of atomic energy, but said we would not stand on "pride of authorship" in demanding the Baruch Plan.

McMahon, Brien. The hydrogen bomb—suggestions for control of superweapons. DAILY CONGRESSIONAL RECORD (Washington) February 2, 1950, v. 96: p. 1366–1372.

Senator McMahon proposed that the nation offer to spend for the next five years two-thirds of its present military outlay—that is, $10 billion a year for five years—on developing peaceful uses of atomic energy and on giving economic aid to all nations who would accept the conditions for an effective U. N. control plan and who would likewise devote two-thirds of their armament spending to the constructive ends outlined in the speech.

Text of the address was reproduced in the *New York Times*, February 3, p. 2, and in VITAL SPEECHES OF THE DAY, February 15, p. 258–263. Reprints may also be obtained from Senator McMahon's office.

Osborn, Frederick H. Basic issues on atomic energy. DEPARTMENT OF STATE BULLETIN (Washington) August 22, 1949, v. 21: p. 247–249.

Reprint of address delivered before the U. N. Atomic Energy Commission on July 20, 1949.

A report on the international control of atomic energy. Prepared for the Secretary of State's committee on atomic energy by a board of consultants. Department of State, Washington pp. 61, publication 2498 (1946).

Second Report of the United Nations Atomic Energy Commission to the Security Council, Sept. 11, 1947 (Department of State pub. 2932).

Third Report of the United Nations Atomic Energy Commission to the Security Council, May 17, 1948 (Department of State pub. 3179).

Tydings, Millard E. The H-bomb. DAILY CONGRESSIONAL RECORD (Washington) February 6, 1950, v. 96: p. 1533–1537.

Senator Tydings introduced a resolution (S. Res. 226) in the U. S. Senate suggesting that President Truman propose an international disarmament conference "to end the world's nightmare of fear."

BOOKS AND PAMPHLETS

American Friends Service Committee. American-Russian relations: some constructive considerations. A report by a working party to the Executive Board of the American Friends Service Committee, July 1949. 29 p. mimeo.

Foreword: "This is a tentative report which is released for discussion and constructive criticism. American Friends Service Committee, 20 South 12th St., Philadelphia 7, Pa."

Contains a proposal to put present stocks of atomic weapons under United Nations Seal, and to halt the concentration of fissionable material pending U. N. A. E. C. certification of legitimate uses for such materials.

Arms and the atom. *Ch. 3 in* Hamilton, Thomas J. Headline series report on the United Nations. (Foreign Policy Association, New York) May 20, 1949. 62 p. (Headline Series no. 75.)

Blackett, Patrick Maynard. Military and political consequences of atomic energy. London, Turnstile Press, 1948. 216 p.

Nobel prize winner, Professor P. M. Blackett, considers the policies of Britain and the United States as unrealistic in their military basis and as likely to be disastrous in their political consequences. The book has been favorably reviewed in both countries, notably, by James P. Warburg in the NEW STATESMAN AND NATION, Oct. 16, and by James R. Newman in the NEW REPUBLIC, Nov. 29. On the other hand, the British delegation at the United Nations, in a 3,500-word report prepared by Richard T. G. Miles, disclaims any official sanction of the author's views.

Brodie, B. The absolute weapon: atomic power and world order. Harcourt, Brace and Company (New York, N. Y.), pp. 214 (1946).

Contents—Introduction: The Common Problem, by F. S. Dunn. Part I. The Weapon: war in the atomic age and implications for military policy by Bernard Brodie. Part II. Political Consequences: the atomic bomb in Soviet-American relations, by Arnold Wolfers; effect on international organization, by Percy Corbett. Part III. Control: international control of atomic weapons, by W. T. R. Fox.

Carnegie Endowment for International Peace. The United Nations Atomic Energy Commission: an historical survey of the period June 1946–March 1947. *International Conciliation* No. 430, Carnegie Endowment for International Peace (New York, N. Y., pp. 166–292, April 1947).

A study of the Commission's organization, policies and reports; texts of resolutions and important statements are given.

Fox, William T. R. Atomic energy and international relations. *In* Ogburn, William F., *ed.* Technology and international relations. Chicago, University of Chicago Press, 1949, p. 102–125.

Fox, W. T. R. The struggle for atomic control. Public Affairs Committee, Inc. (New York, N. Y.), pp. 32 (1947).

A review and analysis of the problem of international control and the United Nations to March 1947.

Lippmann, W. International control of atomic energy. In Masters and Way (eds), One world or none. McGraw-Hill (New York, N. Y.) pp. 79 (1946).

Meyer, C. Jr. Peace or anarchy. Little, Brown & Co. (Boston, Mass., U. S. A.) pp. 233 (1947).

Author, President of the United World Federalists, has a chapter entitled "The Baruch Plan."

Mumford, Lewis. Atomic war—the way out. London, National Peace Council, 1948 (?) 19 p. (Peace Aims pamphlet no. 46.)

Newman, James R. and Byron S. Miller. The control of atomic energy; a study of its social, economic and political implications. New York, Whittlesey House, 1948. 434 p.

This study is the work of the former counsel to the Senate Committee on Atomic Energy and the former Assistant General-Counsel to the Office of War Mobilization and Reconversion.

Possony, S. T. Atomic bomb: political hopes and realities. *Review of Politics* (Notre Dame, Ind.) 8:147–167 (April 1946).

A review of proposals before the United Nations for international control of atomic energy; analysis of proposals for world government; the consequences of failure to agree.

Shils, E. A. The atomic bomb and world affairs. National Peace Council (London, England) Pamphlet No. 45, pp. 79 (1948).

Background of the U. S. and U. S. S. R. atomic energy control proposals with suggestions for resolving current differences of opinion and approach. Also found in condensed form in *University of Chicago Law Review* 15:855–876 (Summer 1948) and *Bulletin of the Atomic Scientists* (Chicago, Ill.) (July 1948).

Shotwell, J. T. The control of atomic energy under the charter. In Proceedings of the American Philosophical Society (Philadelphia, Pa.), pp. 79 (1946).

University of Chicago Round Table. Atomic energy and the United Nations. An NBC radio discussion by David Cavers, Herman Finer, and Thorfin Hogness. No. 553, Oct. 24, 1948. 33 p.

Includes a summary of the Western proposals for international atomic energy control; Soviet proposals * * *. The Third Report of the UN Atomic Energy Commission; and excerpts from recent UN General Assembly debates on atomic energy.

Viner, J. The implications of the atomic bomb for international relations. *In Proceedings of the American Philosophical Society* (Philadelphia, Pa.), pp. 79 (1946).

Vyshinskiĭ, Andreĭ. The Soviet position on prohibition of atomic weapons and international control of atomic energy; speeches at the fourth session of the United Nations General Assembly, November 1949. Issued by the Information Bulletin of the Embassy of the Union of Soviet Socialist Republics (2112 Massachusetts Ave. NW., Washington, D. C.), 1950. 56 p.

Periodical and Newspaper References

Annals, American Academy of Political and Social Science. (Philadelphia, Pa.) (January 1947)

Issue devoted to theme of "Social Implications of Modern Science." The Atomic Crusade and Its Social Implications, by A. H. Compton; The Atomic Dilemma, by B. Brodie; World Government and the Control of Atomic Energy, by H. W. Briggs; Civil Liberties in the Atomic Age, by R. E. Cushman; Law and Atomic Energy, by E. B. Stason.

Atomic energy. INTERNATIONAL AFFAIRS (London) v. 25; April 1949: p. 199.

H. E. Wimperis, British scientist, in reviewing Blackett's book admits its pro-Russian bias, but thinks it fortunate that the United Nations in its future deliberations may consider the situation in the light of what the book advances.

Atomic peace and atomic politics. NEW REPUBLIC (New York) v. 122, April 17, 1950: p. 5–13.

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Baldwin, Hanson W. The hydrogen bomb. *New York Times,* April 16, 17, 18, 19, 1950.

Barnard, Chester I. SCIENTIFIC AMERICAN (New York) v. 181, November 1949: p. 11–13.

"Does the atomic explosion in Russia require the U. S. to modify its position in regard to the international control of atomic energy?"

Baruch, Bernard Mannes. Statements on atomic energy in Secretary Wallace's letter of July 23, 1946. *New York Times,* September 20, 1946.

Reply by the U. S. Delegate to the United Nations Atomic Energy Commission to Mr. Wallace's letter to the President dated July 23, 1946, criticizing certain aspects of U. S. atomic energy proposals. (See Wallace, H. W.)

Bernal, J. D. The atom for war or peace? SOVIET RUSSIA TODAY (New York) February 1950: p. 14–15+.

The author, a Fellow of the Royal Society, discusses the American and Russian proposals for atomic energy control, and calls on labor to rally against the new atom bomb race. Published first in January issue of *Labour Monthly* (London).

Bernstein, David. The cold peace. Outline for an unwritten book. HARPER'S MAGAZINE (New York) v. 198, April 1949: p. 21–23.

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Bethe, Hans A. The hydrogen bomb. SCIENTIFIC AMERICAN (New York) April 1950, v. 182: p. 18–23.

Breaking the atomic deadlock. NEW REPUBLIC (New York) v. 122, April 3, 1950: p. 5–17.

"This is the first of three articles prepared by the editors of the NEW REPUBLIC, dealing with the greatest single issue of our times: international agreement on atomic energy . . .

"Published with this issue of the NEW REPUBLIC is a special section giving essential facts about weapons involving atomic explosions."

Cavers, David F. An interim plan for international control of atomic energy. BULLETIN OF THE ATOMIC SCIENTISTS (Chicago) v. 6, January 1950: p. 13–16.

This proposal presented by Dr. Cavers, Professor of Law at Harvard University, recognizes and explores the altered status created by the Soviet achievements in atomic energy.

Cavers, David F. New life for the UNAEC. BULLETIN OF THE ATOMIC SCIENTISTS (Chicago), December 1948, v. 4: pp. 355–358, 362.

"Dr. Cavers, a member of the Faculty of the Harvard Law School, sees in the exploration of concrete problems a hope of reconciling divergent views on atomic energy control."

Cavers, D. F. Atomic power versus world security. BULLETIN OF THE ATOMIC SCIENTISTS (Chicago, Ill.), 3:283–288, 302 (October 1947).

Professor Cavers, of the Harvard University Law School, discusses at length the idea of a moratorium on large-scale use of atomic energy for power as an element in an international control plan; research uses would not be affected.

Daniel, Cuthbert, *and* John L. Balderston. A proposal for an atomic armistice. BULLETIN OF THE ATOMIC SCIENTISTS (Chicago), v. 6, January 1950: p. 17+

This letter, addressed to the delegates of the United Nations General Assembly on November 12, 1949, by two engineers formerly employed at Oak Ridge National Laboratory, endorses President Romulo's appeal for a short-term armistice.

Dean, Vera Micheles. Atomic issue overshadows UN Assembly. FOREIGN POLICY BULLETIN (New York), v. 28, September 30, 1949: p. 1–2.

Debates in U. N. General Assembly: Soviet Union reverses position on quotas. BULLETIN OF THE ATOMIC SCIENTISTS (Chicago), February 1950, v. 6: p. 43–49.

A reprint of significant passages from Mr. Vishinsky's speech in the General Assembly of the U. N., on November 23, and from the speeches which followed it.

de Rose, Francois. The atomic energy debate at Paris: a French appraisal. BULLETIN OF THE ATOMIC SCIENTISTS (Chicago), v. 5, January 1949: p. 9–11.

An unofficial expression of opinion by M. Francois de Rose, who has been acting French Representative on the UNAEC since its inception.

FAS suggests working control plan to UNAEC. BULLETIN OF THE ATOMIC SCIENTISTS (Chicago), v. 5, March 1949: p. 96.

Statement released by the Federation of American Scientists on February 28, 1949. This issue also contains a letter from FAS to Trygve Lie proposing United Nations distribution of isotopes. (See p. 79, 95.)

Fox, W. T. R. "Middle Run" planning: atomic energy and international relations. BULLETIN OF THE ATOMIC SCIENTISTS (Chicago, Ill.), 4:227–232 (August 1948).

Friedwald, E. M. The atomic deadlock could be broken. BULLETIN OF THE ATOMIC SCIENTISTS (Chicago), December 1948, v. 4: p. 363–367.

A symposium consisting of articles by E. M. Friedwald, N. F. Mott, M. L. Oliphant and H. C. Urey, reprinted from DISCOVERY.

Gromyko, Andrei A. The "veto" and the aggressive North Atlantic bloc. USSR INFORMATION BULLETIN (Washington), v. 9, April 22, 1949: p. 237–243, 287.

Under the subheading "International Control over Atomic Energy," Gromyko explains the official Russian position in his speech of April 13 before the General Assembly of the U. N.

Hamilton, Thomas J. Atom bomb stalemate. FREEDOM AND UNION (Washington), v. 5, January 1950: p. 14–15.

Analyzes situation in the United Nations.

The H-bomb crisis—Spectrum of opinion. F. A. S. NEWSLETTER (1749 L St. N.W., Washington, D. C.) February 15, 1950: 4 p.

This issue of the NEWSLETTER, published by the Federation of American Scientists, contains the President's directive of February 1 to AEC to proceed with work on the hydrogen bomb, and a survey of public opinion on the subject.

The hydrogen bomb. THE ECONOMIST (London) February 4, 1950, v. 158: p. 241–243.

Points out danger that an accord with Russia covering no more than the atom bomb would only increase the risk of war * * *. Says hydrogen bomb presents a new opening to examine once again whether there is any possibility of a general *détente* between the east and west.

Interim report on six-power discussions on control of atomic energy. CURRENT DEVELOPMENTS IN UNITED STATES FOREIGN POLICY (Brookings Institution, Washington, D. C.) v. 3, October 1949: p. 17–18.

Statement of the eight topics discussed; also a statement of principles submitted with each topic.

Kennan, George F. Is war with Russia inevitable? Five solid arguments for peace. READER'S DIGEST (Pleasantville, N. Y.) March 1950: p. 1–9.

Kihss, Peter. United Nations atomic energy news. BULLETIN OF THE ATOMIC SCIENTISTS (Chicago) v. 5, Jan. 1949: p. 29–31.

"Mr. Kihss * * * here surveys the debates on atomic energy held in the United Nations General Assembly at Paris, between October 7 and the close of the session."

McMahon, Brien. Let's tell the atom bomb story. UNITED NATIONS WORLD MAGAZINE (New York), June 1949, v. 3: p. 11–12.

Senator McMahon, Chairman of the Joint Congressional Atomic Energy Committee, thinks international control can be furthered if there is less secrecy about the bomb both at home and abroad.

Military and political consequences of atomic energy: some views on Blackett's book. BULLETIN OF THE ATOMIC SCIENTISTS (Chicago), v. 5, February 1949: p. 34–43, 50.

Blackett's apologia for the Soviet position, by Edward A. Shils.

Blackett's analysis of the issues, by Philip Morrison.

Comment on Blackett's book, by Brien McMahon.

An English scientist exposes atomic diplomacy, by M. Marinin (from a review which appeared in Pravda, November 22, 1948).

Morgenthau, Hans J. The H-bomb and after. BULLETIN OF THE ATOMIC SCIENTISTS (Chicago), March 1950, v. 6: p. 76–79.

Mumford, L. Atom bomb: "miracle" or catastrophe. *Air Affairs* (Washington, D. C.), 2: 326–345 (July 1948).

Review of the implications of current international impasse and presentation of a series of proposals to both the U. S. A. and the U. S. S. R. for resolving differences in control of atomic energy and other questions.

New proposals for the regulation of atomic weapons. CURRENT DEVELOPMENTS IN UNITED STATES FOREIGN POLICY (Brookings Institution, Washington, D. C.), v. 3, February 1950; p. 4–10.

Discusses plans proposed in Congress by Senators McMahon and Tydings; statement of policy expressed by Secretary Acheson; address by President Truman at Alexandria, Virginia, on February 22; and the article by State Counselor Kennan (see no. 413 on this list).

Oppenheimer, J. Robert. The open mind. BULLETIN OF THE ATOMIC SCIENTISTS (Chicago) v. 5, January 1949; p. 3–5.

A speech before the Rochester Institute for International Affairs, in which Dr. Oppenheimer discusses the spirit which should guide American conduct in the present impasse over the international control of atomic energy.

Osborn, Frederick. Can we control atomic energy? Technically, yes, says our deputy on the U. N. commission. Politically it is impossible now. *New York Times Magazine*, October 30, 1949; p. 12, 31.

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A reevaluation of the atomic bomb as an instrument of war from both the strategic and political viewpoint. This article is prompted by recent statements of President Truman and Mr. Churchill.

Premier Stalin's answers. *Pravda* (Moscow, U. S. S. R.), p. 1 (October 30, 1946).

A reply to written questions by a correspondent representing the U. S. Associated Press; Premier Stalin's remarks concerning the necessity for strict international control of atomic energy.

A proposal for atomic peace. NEW REPUBLIC (New York), November 7, 1949, v. 121: p. 5–7.

Thinks the weakness of the Lilienthal plan is that it is a "technical plan intended to achieve a political objective." Advocates a political treaty that tends to promote peace *now* by outlawing the bomb.

Ridenour, Louis N., Jr. The bomb and Blackett. WORLD POLITICS (New Haven) v. 1, April 1949: p. 395–403.

A review of "Fear, War and the Bomb" published jointly in SCIENTIFIC AMERICAN and WORLD POLITICS.

Ridenour, Louis N. The hydrogen bomb. Presenting an account of the theoretical background of the weapon and a discussion of some questions it has raised in regard to our present policy of security. SCIENTIFIC AMERICAN (Washington) v. 182, March 1950: p. 11–15.

Louis N. Ridenour, a physicist who worked on radar development during the war, is Dean of the Graduate College of the University of Illinois.

Swing, Raymond. Prescription for survival. THE NATION (New York) v. 170, February 18, 1950: p. 151–154.

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Szilard, Leo. Can we have international control of atomic energy? BULLETIN OF THE ATOMIC SCIENTISTS (Chicago) v. 6, January 1950: p. 9–12, 16.

Address given December 10, 1949, to the Rochester Institute of International Affairs, Rochester, N. Y.

Thirring, Hans. Die geschichte der atombombe (Vienna, 1946) Chapter 42 reprinted in Bulletin of the Atomic Scientists (Chicago) March 1950, v. 6: p. 69.

University of Chicago Round Table. Peace with Russia—realism or unrealism? An NBC radio discussion by Harrison Brown, William Henry Chamberlin, Malcolm Sharp and Gilbert White. Including The problem of the hydrogen bomb, or How to make a miniature star on earth, by Waldemar Kaempffert. No. 619, January 29, 1950. 16 p.

In this broadcast the H-bomb is termed the final challenge of peace or universal destruction.

Urey, H. C. An alternative course for the control of atomic energy. *Bulletin of the Atomic Scientists* (Chicago, Ill.) 3:139–142, 166 (June 1947).

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Vishinsky, Andrei Y. United States and Great Britain are undermining the United Nations. Proposals for peace and control of atomic weapons. VITAL SPEECHES OF THE DAY (New York) v. 16, October 15, 1949: p. 5–8.

Speech delivered at the General Assembly of the United Nations, Flushing Meadows, N. Y., September 23, 1949.

Wallace, H. W. Letter to President Truman on U. S. foreign policy and the international control of atomic energy. *New York Times*, September 18, 1946. (See Baruch, B. M.)

Who prevents atomic agreement? NEW REPUBLIC (New York) v. 122, April 10, 1950: p. 5–10.

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