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United Nations Secretary General

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EFFECTS OF THE POSSIBLE USE OF NUCLEAR WEAPONS AND THE SECURITY AND ECONOMIC IMPLICATIONS FOR STATES OF THE ACQUISITION AND FURTHER DEVELOPMENT OF THESE WEAPONS

UNITED NATIONS

Department of Political and Security Council Affairs

EFFECTS OF THE POSSIBLE USE OF NUCLEAR WEAPONS AND THE SECURITY AND ECONOMIC IMPLICATIONS FOR STATES OF THE ACQUISITION AND FURTHER DEVELOPMENT OF THESE WEAPONS

Report of the Secretary-General
transmitting the study
of his consultative group

UNITED NATIONS
New York, 1968

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FOREWORD

1. By General Assembly resolution 2162 A (XXI) of 5 December 1966, the Secretary-General was requested to prepare, with the assistance of qualified consultant experts, a report on the effects of the possible use of nuclear weapons and on the security and economic implications for States of the acquisition and further development of these weapons.

2. In pursuance of this resolution, I appointed a group of consultant experts whose members were: Wilhelm Billig, Chairman of the State Council for Peaceful Uses of Atomic Energy, Poland; Alfonso León de Garay, Director of the Genetics and Radiobiology Programme, National Nuclear Energy Commission, Mexico; Vasily S. Emelyanov, Chairman of the Commission on the Scientific Problems of Disarmament of the Academy of Sciences of the Union of Soviet Socialist Republics; Martin Fehrm, Director General of the Research Institute of Swedish National Defence; Bertrand Goldschmidt, Director of External Relations and Planning, Atomic Energy Commission, France; W. Bennett Lewis, Senior Vice-President, Science, Atomic Energy of Canada Limited; Takashi Mukaibo, Professor, Faculty of Engineering, University of Tokyo, Japan; H. M. A. Onitiri, Director, Nigerian Institute of Social and Economic Research, University of Ibadan, Nigeria; John G. Palfrey, Professor of Law, Columbia University, New York, United States of America; Gunnar Randers, Managing Director, Norwegian Institute for Atomic Energy; Vikram A. Sarabhai, Chairman, Atomic Energy Commission of India; Sir Solly Zuckerman, Chief Scientific Adviser to Her Majesty's Government, United Kingdom. Mr. Mullath A. Vellodi, Deputy to the Under-Secretary, Department of Political and Security Council Affairs, served as Chairman. He was assisted by members of the Secretariat.

3. The consultant experts, in their personal capacities, have submitted to me a report containing their considered and unanimous views on the various and complex aspects of the subject matter of this report. The consultant experts have approached their task in the spirit of the resolution of the General Assembly and it gives me very great satisfaction that they were able through co-operation and understanding to come up with a unanimous report. What makes the report particularly valuable is the fact that, in trying to reach unanimity, the expert consultants have not avoided sensitive or even controversial issues. This is extremely significant because the value of the report lies in its clear and fair exposition of the problem. I am very pleased to be able to endorse their findings. I wish also to record my most sincere appreciation for their invaluable assistance in carrying out an important and delicate task.

4. I have therefore decided to transmit their report in full to the General Assembly as the report called for by resolution 2162 A (XXI). It is with a sense of gratification that I submit this report. As I wrote last year in the introduction to the annual report on the work of the Organization, "I believe that the time has come for an appropriate body of the United Nations to explore and weigh the impact and implications of all aspects of nuclear weapons . . . To know the true nature of the danger we face may be a most important first step towards averting it". It is my hope that this report, and the ensuing debate by the General Assembly, will not only provide a deeper and clearer understanding of the effects of the nuclear arms race but also positively contribute to the search for ways to bring it to an end.

U THANT
Secretary-General

CONTENTS

ANNEXES

LETTER OF TRANSMITTAL

6 October 1967

We have the honour to submit herewith a unanimous report on the effects of the possible use of nuclear weapons and on the security and economic implications for States of the acquisition and further development of these weapons which we were invited to prepare in pursuance of General Assembly resolution 2162 A (XXI).

The report was drafted during meetings held in Geneva between 6 and 10 March and between 26 June and 5 July 1967, and finalized at meetings held in New York between 2 and 6 October 1967. Mr. M. A. Vellodi, Deputy to the Under-Secretary, Department of Political and Security Council Affairs of the United Nations Secretariat, served as Chairman at all the sessions.

The Group of Consultant Experts wish to express their gratitude for the valuable assistance they received from the members of the Secretariat.

(*Signed*)

Wilhelm BILLIG

Alfonso LEÓN DE GARAY

Vasily S. EMELYANOV

Martin FEHRM

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(*Signed*)

Takashi MUKAIBO

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Sir Solly ZUCKERMAN

The Secretary-General
United Nations
New York

I. EFFECTS OF THE POSSIBLE USE OF NUCLEAR WEAPONS

INTRODUCTION

1. The enormity of the shadow which is cast over mankind by the possibility of nuclear war makes it essential that its effects be clearly and widely understood. It is not enough to know that nuclear weapons add a completely new dimension to man's powers of destruction. Published estimates of the effects of nuclear weapons range all the way from the concept of the total destruction of humanity to the belief that a nuclear war would differ from a conventional conflict, not in kind, but only in scale. The situation, however, is not as arbitrary as opposing generalizations such as these might suggest. There is one inescapable and basic fact. It is that the nuclear armouries which are in being already contain large megaton weapons every one of which has a destructive power greater than that of all the conventional explosive that has ever been used in warfare since the day gunpowder was discovered. Were such weapons ever to be used in numbers, hundreds of millions of people might be killed, and civilization as we know it, as well as organized community life, would inevitably come to an end in the countries involved in the conflict. Many of those who survived the immediate destruction, as well as others in countries outside the area of conflict, would be exposed to widely-spreading radio-active contamination, and would suffer from long-term effects of irradiation and transmit, to their offspring, a genetic burden which would become manifest in the disabilities of later generations.

2. These general propositions, whether set out dispassionately in scientific studies or directed as propaganda, have been proclaimed so often that their force has all but been lost through repetition. But their reality is none the less so stark that, unless the facts on which they are based are clearly set out, it will not be possible to realize the peril in which mankind now stands.

3. The purpose of the first section of this report is to provide a picture of the destructive power of nuclear weapons and of the consequences of their use. It gives a brief account of the destruction wrought in Hiroshima and Nagasaki by the explosion of single and relatively small nuclear weapons. These two disasters are the only examples of the actual use of nuclear weapons in war, and they provide direct information about the kind of casualties caused by nuclear explosions. The first section also outlines some theoretical studies of the physical effects of

much larger nuclear weapons on centres of population and on the civilian economy, as well as the effect such weapons would have on major military targets. It deals too with the implications of so-called tactical nuclear warfare, that is to say of field warfare in which nuclear weapons are used. To achieve a measure of realism, most of these studies were related to actual, as opposed to hypothetical geographical areas, towns or cities, that is to say cities with a particular pattern of public services, communications and food supply. In a widespread exchange of strategic nuclear weapons many cities would suffer devastation similar to that of the examples studied, with a cumulative interacting effect which would greatly exceed the simple addition of the direct results of individual attacks. Accepting that an attacker could always have the advantage over a defender in terms of surprise and weight of attack, no attempt has been made to complicate the general story by analysing the extent to which an ABM defence, together with civil defence measures, might reduce the scale of damage and the number of casualties which would result from a nuclear attack. It is enough to note that there is no active defence system in sight which would prevent all nuclear weapons from reaching their selected targets.

4. Some technical details and general characteristics of nuclear explosions are set out in annex I to this section. The genetic effects of nuclear radiation are discussed in annex II.

HIROSHIMA AND NAGASAKI

Physical effects

5. The first atomic bomb to be used in warfare had a yield of nearly twenty kilotons, that is to say it had an explosive force equivalent to nearly 20,000 tons of conventional chemical explosive (e.g., TNT). It was detonated at approximately 550 metres above Hiroshima on 6 August 1945. On 9 August a second atomic device, with a similar yield, was detonated at about the same height over Nagasaki. In Hiroshima, destruction was concentric around the centre of a spreading city whose population was about 300,000. Within seconds, a rapidly growing fire-ball developed into a mushroom-like cloud, supported, as it were, on a column of black smoke, and the heat radiating from the fire-ball caused thousands of fires.

6. By comparison with Hiroshima, Nagasaki was a narrow city surrounded by hills and open to the sea in only one direction, with a population of about 87,000 people living within three kilometres from the centre. The immediate effects of the explosion were the same, but the area of destruction and fire differed in accordance with the different layout of the cities. In both cases the heat of the explosion was so intense that, up to a distance of about a half kilometre from the centre of the disaster, the surface of domestic ceramic roof tiles melted and firing of domestic wooden houses, by direct radiation, was observed up to one and a half kilometres.

7. There are varying estimates of the casualties[1] in Hiroshima and Nagasaki and it has proved difficult to estimate the exact numbers of exposed people who may have died after escaping from the city. Available estimates are that 78,000 were killed and 84,000 injured in Hiroshima, and that 27,000 were killed and 41,000 injured in Nagasaki. In addition, there were thousands missing in both towns. Most of the immediate fatal casualties were caused by the violent disruption of residential and office buildings. In Hiroshima 60,000 houses were completely or partially destroyed. Wooden houses within two and a half kilometres radius were carried away, while brick buildings were turned into heaps of rubble. Severe damage to houses occurred as far out as eight kilometres. Walls, doors, bricks, glass, furniture and other debris hurtled through the air, crushing or damaging everything in their way. Moderately close to "ground-zero", by which is meant the point on the ground directly below the explosion, buildings were pushed over bodily, and at greater distances were leaning away from the source of the blast.

8. No exact information is available concerning the relative importance of blast, burns and nuclear radiation as the causes of fatalities in these bombings. Burn injuries constituted the major problem in medical care. People exposed in the open had been severely burned, injuries from direct radiation being incurred as far out as about two kilometres from the centre of the zone of destruction. From the day after the bombing, burns accounted for about one half of all the deaths. At the Kameyama Hospital in Hiroshima 53 per cent of the patients who received burns at one kilometre died within the first week and 75 per cent within two weeks. The peak mortality occurred on the fourth day. Another peak in deaths occurred in the third and the fourth week, when complications, especially those associated with radiation injury, set in. Twenty days after the attack it was found that, among burned survivors, the great majority (80-90 per cent) had suffered "flash" burns from the immediate absorption of the thermal radiation of the explosion on the exposed skin; some 5-15 per cent had suffered both flash and flame burns; a very few (2-3 per cent) had suffered flame burns only.

9. The explosion over Hiroshima rapidly led to a firestorm[2] which lasted for about six hours and which burned out an area of twelve square kilometres of the town. Within about two to three hours a wind, which started twenty minutes after the detonation of the bomb, reached a velocity of fifty to sixty kilometres per hour, blowing towards the burning city from all directions. Seventy per cent of the fire-fighting machines in Fire Brigade stations were rendered unusable, and 80 per

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[1] The population and casualty figures referred to are taken from public announcements of local governments in Hiroshima and Nagasaki, six months after the explosions, based on reports by the survey mission of the National Research Council, Japan.

[2] A firestorm is not a special characteristic of nuclear explosion. It may be a consequence of a forest fire or an incendiary bomb attack, with high inward winds produced largely by the updraft of the heated air over an extensive burning area. The incidence of firestorms is dependent on conditions at the time of the attack, including the local availability of fuel.

cent of the fire-fighting personnel were unable to respond to the emergency. The loss of water pressure through the breaking of pipes, mainly due to the collapse of buildings, contributed greatly to the additional destruction by fire. But even if men and machines had survived the blast, many fires would have been inaccessible within one and a half kilometres from ground-zero.

10. About 45,000 of the fatal casualties in Hiroshima died on the day of the explosion, and some 20,000 during the following four months, as a result of traumatic wounds, burns and radiation effects. There are no estimates of the numbers who may have died from the effects of induced radio-activity experienced during rescue work in the city. Most of the medical facilities in Hiroshima were in the devastated area of the city, and the methods adopted for treating casualties were consequently far below standard. Difficulties were aggravated by shortage of supplies and equipment, and by the extraordinary demands made on crippled medical staffs. Next to immediate medical problems, the most serious challenge to those who had survived the direct effects of the explosion, were problems of water supply, housing and food. Electrical distribution systems suffered severely, first by damage to overhead lines, and secondly by damage to switch gear and transformers caused by collapse of the structures in which they were located. To people who were not immediate casualties these difficulties compounded the profound psychological effects of the disaster of which they were part. Even twenty years after the bombings there is an excessive sensitivity of the people to the thought of radiation hazard, leading to difficulties in obtaining agreement about the siting of nuclear power plants.

Long-term radiation effects

11. Apart from the effects which ionizing radiation had on the immediate victims of the explosions, the survivors were also exposed to the hazards of the radiation both in terms of latent disease occurring in the individual (somatic effects) and of changes in hereditary material (genetic effects). It had been suspected for some time that exposure to repeated moderate doses of nuclear radiation is conducive to leukaemia, a disease which is associated with a malignant over-production of white blood cells. A study of the survivors of the two nuclear explosions, over Hiroshima and Nagasaki, shows that the disease can undoubtedly result from a large single (acute) dose of radiation. The incidence of leukaemia in the survivors of Hiroshima and Nagasaki was observed to be increasing in 1948. It reached a peak in 1950-1952. Although it seems to have decreased somewhat since then, it still remains much higher than in the unexposed population of the rest of Japan. While the incidence of the disease increased in all age groups, it did so rather more sharply in young people. The incidence in survivors was up to fifty times greater in those within about one kilometre of the explosion than in people who were further away. It was ten times greater for those within one and one and a half kilometres than for those between two and ten kilometres from ground-zero.

12. A continuing study of the survivors of the two Japanese disasters has also suggested an increased incidence for other kinds of malignant cancer, particularly cancer of the thyroid, and not just leukaemia, which has a much shorter latent interval. There is also a hint, but as yet no more than a hint, that the average expectation of life is less in the survivors of the exposed population whether or not they suffered malignant disease. This is an effect of radiation which has been proved in experimental animals. The indications are stronger that a significantly high proportion of the babies born to women who were pregnant when exposed to the explosion, and who survived, had heads smaller than average size, and that some of these suffered severe mental retardation.

13. Insufficient time has passed since these two nuclear disasters to determine what genetic changes, if any, were induced in the survivors. In any case, although long-term genetic effects would indeed be consequences of radiation in nuclear warfare, such effects are of prime concern only where the acute effects can be disregarded, i.e., in areas far removed from the immediate target areas in a nuclear war or under conditions of intense testing of nuclear weapons in the atmosphere. Hence for the purpose of this report, it has not been thought necessary to discuss fully the present state of knowledge about the genetic effects of ionizing radiation. Some facts concerning these effects are given in annex II. All that need be noted here is that radiation from nuclear explosions can cause genetic mutations and chromosome anomalies which may lead to serious physical and mental disabilities in future generations. These effects may arise either from the radiation released in the first few instants after a nuclear explosion or from that released through the later radio-active decay of the substances contained in "fall-out" from the explosion. In this connexion it should be noted that there was no significant local fall-out in either Hiroshima or Nagasaki since, in both cases, the explosions occurred fairly high in the atmosphere.

THE SIGNIFICANCE OF THE POSSIBLE USE OF NUCLEAR WEAPONS IN FUTURE WARS

14. In all wars, advancing armies have sought to capture vital enemy objectives, such as cities, industrial zones and food producing areas, as well as to command the transport system linking them. Air warfare has made it possible to attack and destroy such targets without first defeating the defending armies. The obliteration of the distinction between the "front" or the "rear" of a war zone, which came about as a result of the air offensives of the Second World War, has now been compounded by the advent of nuclear weapons. Those who defined the two Japanese targets for the first and only atomic bombs yet used in war held that the bombs should be used so as to create the maximum psychological effect, and thus break the will of the Japanese people to continue the fight. Some present-day military theorists who write about nuclear war speak of attacks on cities taking place simultaneously with, or even before, attacks on armed forces and specific military targets.

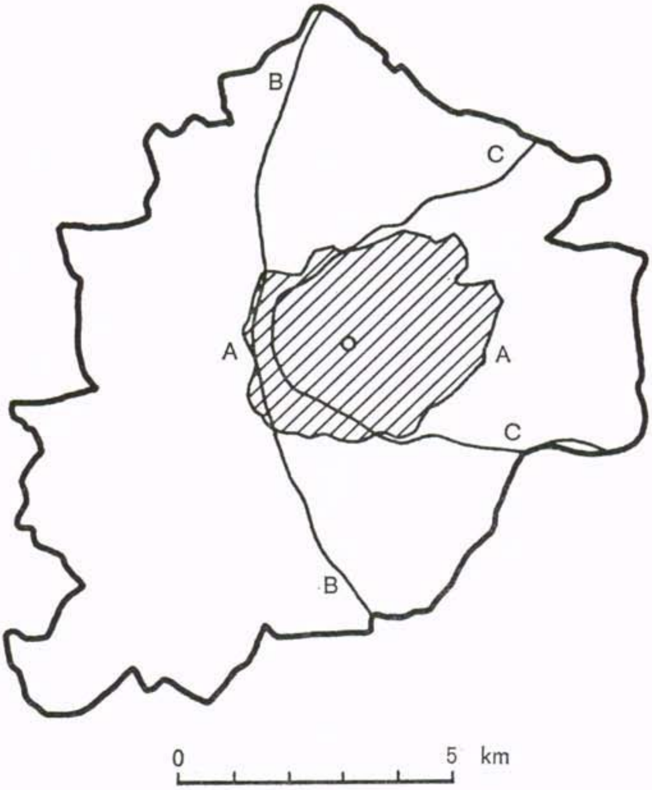
15. It is therefore necessary to build up a picture of what would happen if a large city were attacked not with kiloton weapons of the kind used on the two Japanese cities but with the much more powerful hydrogen bombs or fusion bombs which are available now and whose yield is usually expressed in megatons, i.e., unit yields equivalent to one million tons of chemical explosive. Because of the nature of nuclear weapons all their separate destructive effects, whether immediate or delayed, could never be maximized in a single explosion. For example, the areas affected by blast, thermal radiation and initial nuclear radiation would be appreciably smaller for a ground-burst than an air-burst of the same energy yield. On the other hand, a ground-burst would be accompanied by early radio-active fall-out, which would be much less for an air-burst. With air-bursts, the relative importance of the various effects would depend on the height of the burst.

16. Since every city has its own individuality, its own pattern of services, communications and food supplies, a realistic picture of what would happen cannot be derived unless one considers a real city, and analyses the effects zone by zone, taking into account differences between them in population density, function and so on. One such study was made of a city, with a population of just over one million people, which extended in all directions for about eight to ten kilometres (i.e., with a surface area of some 250 sq. km. or about 100 sq. miles), and attacked, it was assumed, with a single one-megaton nuclear weapon, burst at ground level. Using the experience of Hiroshima and Nagasaki, and estimating also on the basis of the results of carefully designed weapons effects experiments, the following figures of casualties emerged:

Killed by blast and fire	270,000
Killed by radio-active fall-out	90,000
Injured (of whom 15,000 were in the area of fall-out and thus exposed to the effects of radiation)	90,000
Uninjured (of whom 115,000 were in the area of fall-out)	710,000

17. Approximately one third of all the inhabitants would have been killed as a result of blast and fire or from a radiation dose received in the first two days. One third of a million dead is approximately the same number of civilians who were killed by air raids both in Germany and in Japan during the whole of the Second World War. Practically all the inhabitants of the central area of the city, an area of about six by five kilometres, would have been killed, mainly as a result of the destruction caused by blast and fire. Any who were not immediately killed in the central area would have died from nuclear radiation. At the outer boundary of the central area (hatched area, figure I) the proportion of casualties in the population would fall to 75 per cent, and would then continue to fall as the distance from the burst increased. Most of the 90,000 of the city's population who would have suffered non-lethal injuries would have been serious casualties, and, for 15 to 20 per cent of these, rescue operations would have been greatly impeded by radio-active fall-out. In the part of the population who, in this particular

FIGURE I. CASUALTIES
(*within city boundary*)
Distribution of casualties



A is a line enclosing central area 6 × 5 km where practically the whole population would have been killed

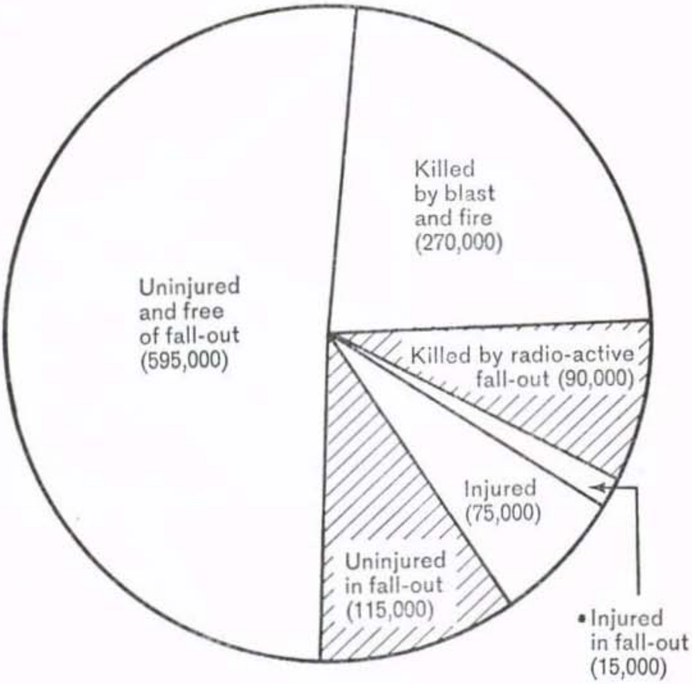
B is a line through a point 2.5 km west of bomb-burst marking limit of fall-out

C marks area inside which a person would have received a lethal dose from fall-out in 48 hours if he had stayed in the open

analysis, were not counted as casualties, 20 per cent would have been subject to radio-active fall-out hazards. Only half of the total population in the city would have been both uninjured and unaffected by fall-out (figure II).

18. The scale of the physical destruction which would be associated with casualties of this order of magnitude is so great that there is no basis of experience which could serve to help describe the instantaneous transformation of a vast living city into a sea of blazing rubble. Every house or building would be damaged; about one third would be completely wrecked, i.e., with damage ranging from utter and complete obliteration, to buildings with more than half their walls down; another one third would be severely damaged, i.e., wrecked for all practical pur-

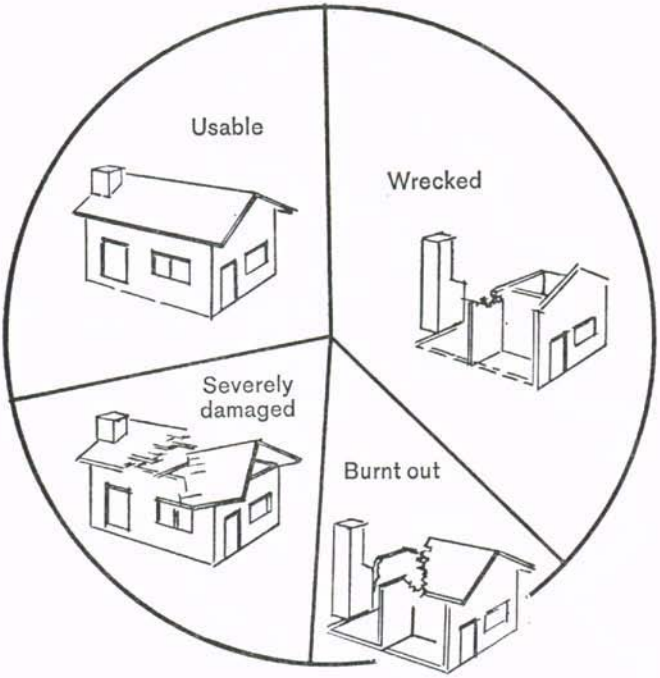
FIGURE II. EFFECT OF A GROUND-BURST MEGATON BOMB ON THE 1,160,000 INHABITANTS



poses, but perhaps providing some temporary shelter if nothing else were available. Only about one third of the original houses would be in any way serviceable, although they would have lost a great part of their roofs, doors and windows (figure III). In many areas, water and gas mains, sewers, and power supplies would have been destroyed. Not a single area would have retained all its essential services (figure IV). Roads would have been erased and even the lightly damaged peripheral areas would very likely be deprived of their water supplies and sources of food supply. It is all but impossible to conceive of the amount of improvisation and reorganization which would be demanded from the shocked survivors in the period immediately following the attack, even though every possible plan had been made to deal with the anticipated results of a possible strike.

19. Against this background of death, injury, destruction and fire, one can see the whole life of a great city being completely disrupted by the explosion of a single megaton bomb. As an organized unit, capable of contributing to a war effort, it would cease to have any meaning. The survivors in different parts of the city would either be in a state of shocked immobility or would be wandering about trying to find some place better than the one where they happened to be when the bomb went off, searching for food, for better shelter, for relatives, for help of any

Figure III. Effect of a ground-burst megaton bomb on accommodation

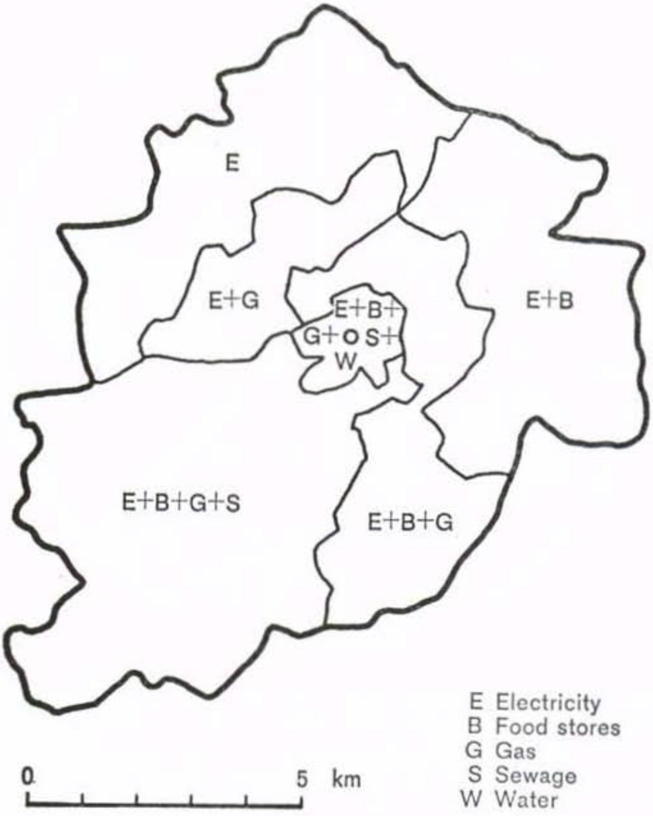


kind. The problems confronting the community would be immeasurably greater than any experience of the Second World War. In hostile circumstances of the kind we are assuming, it would be unrealistic to suppose that only one city would be struck. With many in the same desperate plight, there could be no question of any substantial help being brought to the survivors from outside. In brief, a big city of the size that has been described, a city in which more than a million people lived in an area of about 250 sq. km. would for all practical purposes be eliminated by a single one-megaton weapon ground-burst near its centre. One-megaton bombs are small units in the megaton spectrum; larger weapons, much larger ones, are now stockpiled.

Radio-active contamination

20. Close to the explosion the lethal effects of radiation would be instantaneous. But nuclear weapon explosions also give rise to radio-active fission products and, in the case of a ground-burst, these become mixed with earth particles sucked into the atmosphere. The heavier particles of soil and weapon debris fall back to the ground and settle in the vicinity of the explosion, giving rise to delayed radiation hazards. These particles constitute local radio-active fall-out. For a ground-burst of the type assumed in the foregoing paragraphs, the area of intense fall-out could cover hundreds of square kilometres. Within such an area,

FIGURE IV. SERVICES DESTROYED

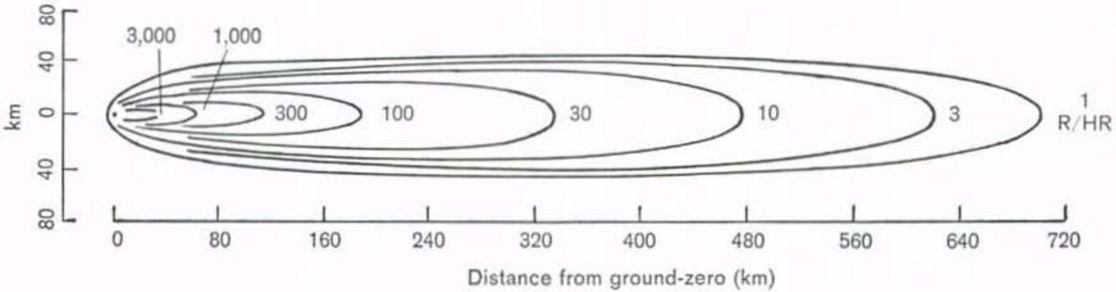


people who were not adequately sheltered and who did not remain under cover until the radio-activity of the fall-out had decayed substantially would be exposed to intensities of radiation sufficient to produce very serious hazards to health. Figure V illustrates a fall-out pattern in the amount of nuclear radiation which an individual would receive in rads per hour for an idealized case of one particular wind speed, in a given direction, following a one-megaton explosion at ground level. Beyond the area of intense fall-out there would be a very much larger zone where significant intensities of radiation would be experienced and where a proportion of the people who were exposed would still be at risk. (For significance of irradiation doses, see annex I, table 4.)

21. The picture painted in paragraphs 16-19 was derived, as already observed, from a detailed analysis of an actual city, taking into account its true layout, and the differential distribution of its population. If, instead, one assumes the general case of a single megaton explosion at a height of about 3,000 metres rather than at ground level, over a hypothetical city having a population of one million people who are evenly

FIGURE V. IDEALIZED UNIT-TIME REFERENCE DOSE-RATE PATTERN FOR EARLY FALL-OUT FROM A 1-MEGATON FISSION YIELD SURFACE-BURST (24 KM/HR EFFECTIVE WIND SPEED)

Effective wind / 24 km/hr (at one hour after explosion)



distributed in a built-up area of twenty by twenty kilometres, the following general conclusions emerge:

(*a*) Within a radius of about three kilometres from the explosion, all buildings would be destroyed and 90 per cent of those inhabiting the area would be casualties (dead and seriously injured);

(*b*) Within a radius of three to six kilometres there would be partial or complete destruction of buildings, and 50 per cent of those inhabiting the area would be casualties. The survivors would have to be evacuated;

(*c*) Within a radius of between six and nine kilometres there would still be heavy destruction to buildings and about 35 per cent of the inhabitants would be casualties.

22. It is estimated that 40 per cent of the total population of such a city would be casualties as a result of blast and fire alone, and that 60 per cent of the entire city would be destroyed. In addition, direct thermal radiation might cause burn casualties and fires as far as ten to fifteen kilometres from ground-zero.

23. For a ten-megaton explosion over such a hypothetical city, the area of complete or serious destruction would cover between 300 and 500 sq. km., that is to say the area of the entire city. Moreover the effects of blast and direct radiation would extend well beyond its boundaries, with heath and forest fires raging up to twenty kilometres from the ground-zero of the explosion. Half of the entire population over an area of radius of some twenty-five kilometres could be expected to die within the first few days as a result of radio-active contamination, even after allowing for some shelter provision.

24. In the case of an air-burst of a twenty-megaton bomb the heat which would result would be intense enough to start fires as far as thirty kilometres from a point of detonation, depending on how clear the atmosphere was at the time, and could endanger the lives of people in an area with a radius of nearly 60 kilometres. It has been estimated that such a device, if exploded over Manhattan, would, in the absence of shelter or evacuation programmes, probably kill 6 million out of New York City's 8 million inhabitants, and lead to an additional one million deaths beyond the city limits. The surface explosion of a twenty-megaton bomb would result in the formation of a crater 75-90 metres deep and 800 metres in diameter. (See reference 3 in annex III.)

ESTIMATE OF EFFECTS OF A NUCLEAR ATTACK ON A REGION OF A COUNTRY

25. A study was made of the likely results of a nuclear attack on a hypothetical industrial region, consisting of nine cities each with populations of over 50,000 inhabitants (some well over), and also containing 140 smaller towns of fewer than 50,000 inhabitants (about sixty of which contained elements of key industry). Assuming that a one-megaton bomb burst at ground level in each of the nine cities, the study showed that

cumulative estimates of casualties provided a very inadequate measure of the over-all effects of the attack. The estimates showed that 20 per cent of the total population, or 30 per cent of the urban population, or 35 per cent of the key-industrial population would be killed. The houses destroyed would be 30 per cent of total, or 40 per cent of urban, or 50 per cent of those occupied by key-industrial population. But cities are not isolated entities; they are linked in a variety of functional ways, being dependent on each other for raw materials of different kinds, as well as for semi-finished and finished manufactured goods. Taking the interaction of effects into account, the study showed that the percentage of key industry in the whole region (i.e., industry with more than local significance) which would be brought to a stop would be between 70 per cent and 90 per cent of the whole. The lower figure of 70 per cent takes account of everything directly destroyed or completely disrupted inside the target cities; the higher figure of 90 per cent includes the areas surrounding the city which would also be indirectly "knocked out" through, for example, failure of communications or supplies of raw materials and food. The more interdependent they are, the larger is the multiplying factor one has to bear in mind when estimating the cumulative effects of the destruction of single cities.

26. Another more general study envisaged a nuclear attack on a small country, extending about 1,000 km in one direction and 500 km in the other, i.e., with an area of 500,000 sq. km. and a population density of 100 people per sq. km. It was assumed that one part of the country was attacked with four nuclear weapons each of twenty megatons. Such an attack would affect about 100,000 sq. km., or some 20 per cent of the country's total expanse by blast, radiation and radio-active contamination. The over-all consequences of the devastation would vary according to the nature of the particular area attacked, e.g., according to whether it contained key cities, sources of electric power, raw materials or whether it was a prime food-producing area. But in every case, economic life would be completely disrupted and the general devastation, including radio-active contamination from low bursts would be such as to prevent any immediate assistance being brought to the devastated areas from outside. In hypothetical studies of this kind it has also been estimated that in the absence of special protection, blast-induced deaths alone resulting from high level 400 ten-megaton bombs aimed at United States metropolitan areas, would eliminate more than half of the total American population of some 200 million people. Even if they were all in substantial fall-out shelters the same proportion would be killed if the weapons were burst at ground level.

27. A Swedish study of the consequences of nuclear attacks against Swedish cities showed that an attack carried out with about 200 weapons, ranging from 20 kilotons to 200 kilotons in yield, would result in 2 to 3 million casualties, i.e., 30 to 40 per cent of the total population of about 7 million people. It also showed that between 30 to 70 per cent of Swedish industry would be destroyed, and that about two thirds of the

industrial workers would receive fatal or severe injuries. The weight of attack assumed in this particular study is relatively heavy, but none the less it corresponds to only a small fraction of the nuclear weapons that are already stockpiled in nuclear arsenals.

28. Swedish studies have also shown that the degree of protection against radio-active fall-out which might be provided by existing buildings in urban and rural areas in Sweden varies greatly. In no region would existing buildings provide adequate protection against the higher levels of radiation which could be experienced in the intense part of the fall-out area. But effective protection might be provided over the greater part of the fall-out area, given there had been time to construct shelters, and to stock them with food and other necessities of life. Even ordinary buildings, if they remain standing, do provide some protection from the radiation caused by fall-out.

29. In addition to a need to protect against external residual nuclear radiation, i.e., radiation emitted later than one minute after a nuclear explosion, there is the further hazard of internal radiation resulting from the ingestion of any radio-active fall-out material that had contaminated food, particularly vegetable food, and in some cases open water supplies. The amount of radio-active material which could be taken into the body by way of contaminated food would exceed that from the inhalation of contaminated air or absorption of contaminated water. The radio-activity of this absorbed material would decay by the emission of damaging nuclear radiation.

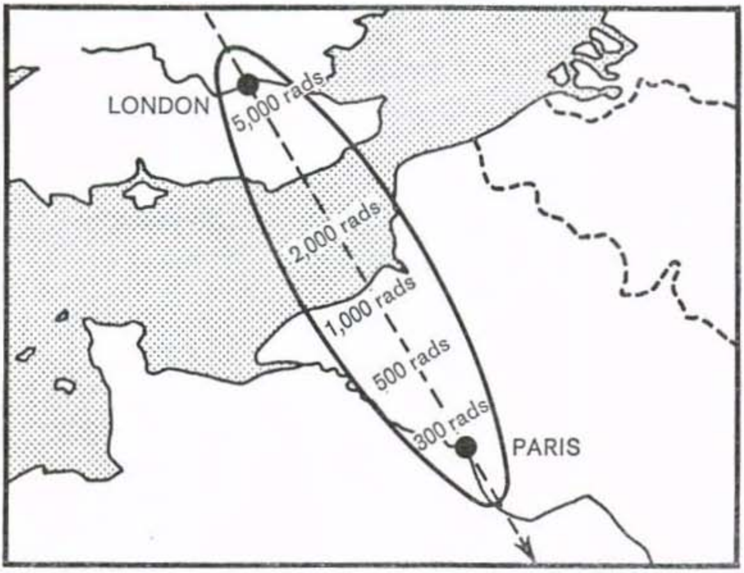
30. Urbanization clearly increases the hazard of radio-active contamination because of the concentration of increasing numbers of inhabitants in comparatively small areas. This applies particularly in Europe. An analysis of about 100 European cities showed that while the larger cities are on average about thirty to fifty kilometres from each other, the smaller cities are on average no more than ten to fifteen kilometres apart. In Germany villages are on average only from one to two kilometres apart. Radio-active contamination, despite a continuous decrease in intensity, would persist for years following a heavy nuclear attack, and would create continuing problems in food-producing areas and to water supplies. Figure VI illustrates the possible far-ranging effect of radio-active fall-out from a twenty-megaton explosion on Hamburg, while figure VII illustrates the similar consequences of a fifteen-megaton explosion on London (see annex I, table 4, for clinical effects of radiation doses). It has been calculated that a twenty-megaton explosion on the American city of Boston would cause such a degree of fall-out over an area with a radius of nearly fifty kilometres that half of the unsheltered people on the fringe of this area would die within forty-eight hours. Even if shelters were provided, high doses of radiation might be received which, even if not fatal, could still produce extensive radiation sickness, as well as long-term somatic and genetic effects.

Figure VI. Estimated fall-out contamination area after 20-megaton nuclear explosion on Hamburg. Radiation dose is given for 48 hours after detonation

EFFECTS ARISING FROM THE USE OF NUCLEAR WEAPONS IN FIELD WARFARE

31. In certain quarters it is still military doctrine that any disparity in the conventional strength of opposing forces could be redressed by using nuclear weapons in the zone of battle. This proposition needs to be considered first in the context that both sides possess these weapons, and second when the situation is asymmetrical and only one side is a nuclear weapons Power. Section III of this report deals with the latter case. In the former, where the situation is symmetrical, carefully conducted and dispassionate theoretical studies of the use of nuclear weapons in field warfare, including analyses of an extensive series of "war games" relating to the European theatre, have led to the clear conclusion that this military doctrine could lead to the use of hundreds, and not of tens, of so-called tactical nuclear weapons in the battlefield area, given that both sides resort to their use. Without going into the details of these studies, it can be firmly stated that, were nuclear weapons to be used in this way, they could lead to the devastation of the whole battle zone.

FIGURE VII. ESTIMATED FALL-OUT CONTAMINATION AREA AFTER A 15-MEGATON NUCLEAR EXPLOSION ON LONDON. RADIATION DOSE IS GIVEN FOR 36 HOURS AFTER DETONATION



Almost everything would be destroyed; forests would be razed to the ground and only the strongest buildings would escape total destruction. Fires would be raging everywhere. Circumstances such as these would be incompatible with the continued conduct of military operations within the zones of devastation.

32. An offensive on the scale to which all these studies point, over a land battle area with a front of, say, 250 km and 50 km deep, would render hundreds of thousands, even millions, homeless. Such a level of destruction could be achieved with only 100 small nuclear weapons in a European battle area chosen because it did not contain any large towns. With 400 weapons, which is not an unreasonably large number if both sides used nuclear weapons in a battle zone, the physical damage caused would correspond to something like six times that caused by all the bombing of the Second World War—and all sustained in a few days rather than a few years. If one sets aside the profound, even if unquantifiable psychological effects of such an exchange, the resulting chaos would still be beyond imagination.

33. The estimates show that with 100 weapons having an average yield of thirty kilotons (range 5 to 50 kilotons) about one tenth of the assumed typical European battle area would be completely devastated, and about one quarter severely damaged. With 200 weapons about one fifth would be devastated and half of it severely damaged; and with 400 weapons about one third of the area would be devastated and all severely

damaged. Even for only 100 strikes, this represents destruction on an unimaginable scale over an area of about 12,500 sq. km. In another European "war-game" study, a battle was envisaged in which the two opposing sides together used weapons whose total yield was between twenty and twenty-five megatons, in not fewer than 500 and in not more than 1,000 strikes. The nuclear weapons were supposed to have been used against military targets only, in an area of about 25,000 sq. km. In this engagement about 3.5 million people would have had their homes destroyed if the weapons had been air-burst, and 1.5 million if the weapons had been ground-burst. In the former case, at least half of the people concerned would have been fatally or seriously injured. In the case of ground-burst weapons, 1.5 million would have been exposed to lethal doses of radiation and a further 5 million to the hazard of considerable although non-lethal doses of radiation.

34. A question which immediately poses itself is whether military operations would be compatible with destruction of the scale indicated by estimates such as these. A vast civilian population would be involved unless the battle took place in desert conditions. The number of casualties, civilian and military, cannot be easily related, in any precise way, to the population actually in the area at the time of the battle. Because the need to reduce the level of military casualties would dictate tactics of dispersal, the number of nuclear strikes necessary to produce assumed military results would go up very rapidly. Fear and terror, both in the civil and military population, might overwhelm the situation.

35. Military planners have no past experience on which to call for any guide as to how military operations could proceed in circumstances such as these. When such levels of physical destruction are reached, one might well ask what would determine the course of a nuclear battle? Would it be the number of enemy casualties? Would it be the violent psychological reaction, fear and terror, to the horror of widespread instantaneous destruction? Would the chaos immediately bring all military operations to a halt? Whatever the answer to these questions, it is clear enough that the destruction and disruption which would result from so-called tactical nuclear war would hardly differ from the effects of strategic war in the area concerned. The concept of escalation from tactical to strategic nuclear war could have no possible meaning in an area within which field warfare was being waged with nuclear weapons.

36. This picture is not altered if one postulates so-called "clean" nuclear weapons, in place of those which formed the basis of the foregoing studies. Claims have been made about the possibilities of providing, for battlefield use, low yield weapons (say 1 to 10 kilotons) which would release an abnormally high proportion of their energy in blast and nuclear radiation, while producing virtually no radio-active fall-out. "Clean", in this context, is a matter of degree. These suggested weapons would basically rely on a fission reaction so that radio-active fall-out

could never be completely avoided.[3] In any case, the foregoing studies postulated nuclear explosions which yielded minimal radio-active contamination from normal fission weapons. The resulting chaos in the battlefield area was brought about, not by fall-out, but primarily through blast effects. Thus, if "clean" weapons were available for battlefield use it is difficult to believe that similar chaos would not ultimately be produced. Sooner or later the battlefield situation must be expected to become similar to that which the foregoing studies have indicated.

Interdiction targets

37. Were such weapons ever to be used in a war, it is also quite certain that they would not be restricted to the battle zone itself—even if it were assumed that there would not be what is usually referred to as a strategic exchange. It is part of the concept of tactical nuclear warfare that in a purely military campaign they would also be used outside the area of contact in order to impede the movement of enemy forces, the operation of air forces and so on. The objectives which would be attacked in order to achieve these effects are generally called interdiction targets. Theoretical studies of operations of this kind provide a picture of "deep" nuclear strikes whose effects would be hardly distinguishable from a strategic nuclear exchange in which both sides set out from the start to destroy each other's major centres of population. To illustrate what is implied, reference can be made to a single strike in one such study in which it was assumed that the railway installations in a major transport centre were attacked by a single twenty-kiloton bomb, or a single 100-kiloton bomb, in order to make the centre impassable to troops and supplies, and thereby to assist the land battle elsewhere. The railway centre chosen for this study was a city with 70,000 inhabitants living in 23,000 houses in an area of some fifty sq. km. The bomb was assumed to be burst at ground level so as to maximize the effects on the railway lines. This mode of attack, unlike that used against the Japanese cities, would at the same time also maximize local fall-out damage. With the twenty-kiloton bomb, railway tracks would be demolished over a length of about 100 metres, a large amount of spoil from the crater would cover all lines in the vicinity, blockage would be caused by the collapse of road bridges, rail flyovers and buildings out to about a half-mile from the burst. All fuel depots and servicing sheds would be destroyed. With a 100-kiloton bomb the scale of damage would, of course, be greater; about one mile of track would be destroyed or blocked by heavy debris, and the main roads through the town would be completely blocked. The problem of reopening a road or railway would be hampered by a vast

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[3] The same would apply to larger so-called "clean" weapons used in a strategic role. In this case there would in addition be considerable induced radio-activity caused by the capture of neutrons in atmospheric nitrogen, thus producing very long-lived radio-active carbon-14. So far as long-range and long-term fall-out is concerned, this radio-active hazard from so-called "clean" weapons is comparable in importance to that from less "clean" weapons. (The foot-note to annex I, para. 7, applies also to "clean" weapons.)

amount of radio-active debris. It would indeed be so great that it would almost certainly be easier to build a new by-pass round the town. If such attacks formed part of a general "interdiction" programme of bombing, it stands to reason that the transport communication system of a country could be totally wrecked in a very short time, and with it much more as well.

38. The estimated inescapable collateral effects of bombing a single railway centre in such a programme of attacks indicate that most of the industrial and commercial property in the middle of the town would have been destroyed. Fire would have consumed not only houses but also the larger buildings and factories not immediately destroyed by the explosion. A twenty-kiloton bomb in an "interdiction" attack on a town which was a communications centre—and few, if any communication centres are not towns—would kill about a quarter of the 70,000 inhabitants, while a 100-kiloton attack would kill about half. The survivors would have to contend with the same kind of situation as has been depicted in the case of the two Japanese cities bombed in 1945, or the larger city attacked by a one-megaton weapon which has been described above. A programme of "interdiction" attacks on targets behind the zone of contact of opposing armies, if such a programme included communication centres as well as airfields, supply depots, armament factories and so on, would be no different in its effects from those of a widespread so-called strategic nuclear exchange between two opposing Powers.

DETERRENCE OF WAR

39. Nuclear weapons constitute one of the dominant facts of modern world politics. They are at present deployed in thousands by the nuclear weapon Powers, with warheads ranging from kilotons to megatons. We have already witnessed the experimental explosion of a fifty to sixty-megaton bomb, i.e., of a weapon with about 3,000 times the power of the bomb used in 1945 against Japan. Hundred-megaton devices, weapons about 5,000 times the size of those used in 1945, are no more difficult to devise. They could be exploded just outside the atmosphere of any country, in order utterly to destroy hundreds, even thousands, of square kilometres by means of blast and spreading fire. It has been suggested on good authority that in certain geographical circumstances multi-megaton weapons could also be exploded in ships near coastlines in order to create enormous tidal waves which would engulf the coastal belt.

40. The effects of all-out nuclear war, regardless of where it started, could not be confined to the Powers engaged in that war. They themselves would have to suffer the immediate kind of destruction and the immediate and more enduring lethal fall-out whose effects have already been described. But neighbouring countries, and even countries in parts of the world remote from the actual conflict, could soon become exposed to the hazards of radio-active fall-out precipitated at great dis-

tances from the explosion, after moving through the atmosphere as a vast cloud. Thus, at least within the same hemisphere, an enduring radio-active hazard could exist for distant as well as close human populations, through the ingestion of foods derived from contaminated vegetation, and the external irradiation due to fall-out particles deposited on the ground. The extent and nature of the hazard would depend upon the numbers and type of bombs exploded. Given a sufficient number, no part of the world would escape exposure to biologically significant levels of radiation. To a greater or lesser degree, a legacy of genetic damage could be incurred by the world's population.

41. It is to be expected that no major nuclear Power could attack another without provoking a nuclear counter-attack. It is even possible that an aggressor could suffer more in retaliation than the nuclear Power it first attacked. In this lies the concept of deterrence by the threat of nuclear destruction. Far from an all-out nuclear exchange being a rational action which could ever be justified by any set of conceivable political gains, it may be that no country would, in the pursuit of its political objectives, deliberately risk the total destruction of its own capital city, leave alone the destruction of all its major centres of population; or risk the resultant chaos which would leave in doubt a government's ability to remain in control of its people. But the fact that a state of mutual nuclear deterrence prevails between the Super Powers does not, as we know all too well, prevent the outbreak of wars with conventional weapons involving both nuclear and non-nuclear weapon nations; the risk of nuclear war remains as long as there are nuclear weapons.

42. The basic facts about the nuclear bomb and its use are harsh and terrifying for civilization; they have become lost in a mass of theoretical verbiage. It has been claimed that the world has learnt to live with the bomb; it is also said there is no need for it to drift unnecessarily into the position that it is prepared to die for it. The ultimate question for the world to decide in our nuclear age—and this applies both to nuclear and non-nuclear Powers—is what short-term interests it is prepared to sacrifice in exchange for an assurance of survival and security.

II. ECONOMIC IMPLICATIONS OF THE ACQUISITION AND FURTHER DEVELOPMENT OF NUCLEAR WEAPONS

GENERAL CONSIDERATIONS

43. Concern about the development and proliferation of nuclear weapons stems not only from the calamitous effects of possible use but from the consciousness that the immense resources devoted to their production could instead be used, according to the expressed aim of the United Nations, "to promote social progress and better standards of life in larger freedom".[4]

44. To understand the economic implications of embarking on the development of a nuclear armoury it is necessary to become clear about the volume and kind of resources such a step demands. The evaluation needs to be in terms not only of the physical and financial resources absorbed but of the opportunities foregone through devoting these resources to destructive weapons. It is not easy to come by some of the relevant information, and no estimates can be better than illustrative.

45. Any given size of effort will have economic implications which differ according to the nuclear and industrial base from which the programme starts. Moreover, a penalty of the arms race is that no size of programme ever satisfies. Even if it became possible to set a limit to an arsenal of nuclear warheads, their delivery systems and the defence of their bases can absorb effort indefinitely.

46. The magnitude and timing of any programme depends on the base of the country's scientific, technical and industrial capability.

47. Scientific and technical capability determines the country's ability to undertake the problems of:

(*a*) Production of fissile and other material to meet the necessary strict specifications;

(*b*) Warhead assembly and testing;

(*c*) Development and control of the delivery vehicles, whether missile or aircraft units in an effective operating system.

It involves personnel represented by physicists, chemists, metallurgists, mathematicians, engineers, skilled machine tool operators, electricians, pipefitters, welders, sheet-metal workers, furnace and chemical plant

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[4] Preamble of the Charter of the United Nations.

operators, instrument makers and fabricators, who are essential for manufacture and assembly of components to the scientific specifications.

48. Industrial capability is measured by the country's established experience in fields of advanced technology, such as nuclear energy, aviation, electronics and space technology.

49. In arriving at the cost figures presented below, countries possessing the above capabilities have been used as a basis, and it is therefore to be expected that costs would be considerably higher for countries which are less developed and have to devote major efforts to establishing these basic prerequisites. It should also be remembered that whereas the development of nuclear armament by an industrially developed country may mean diverting resources from work that improves a standard of life already rather high, the same development on the part of an industrially developing country may have to be done at the expense of the basic economic needs of a substantial fraction of the population.

50. The estimated costs, supported by some actual figures, for a first generation of simple nuclear warheads together with an unsophisticated delivery-vehicle system indicate that the acquisition of such a system may be within the reach of a number of nations. These cost figures, however, bear hardly any credibility as representing a limit lasting for any significant time, even for an industrialized country. The reasoning is that after having acquired the initial unsophisticated nuclear weapons system, the need to develop less vulnerable and more sophisticated delivery systems seems certain to be felt in order to secure the military and political objectives of the force. It thus seems that the total costs of acquiring a nuclear weapons system over, say, ten years are liable under certain circumstances to be closer to the costs given for the French and United Kingdom systems up to 1969, namely, $8,000 million to $9,000 million than to the $1,700 million to $2,000 million derived below for an unsophisticated system. (Any system employing unorthodox means of delivery, such as a ship or commercial aircraft, has been ruled out as not a viable course for any nation to pursue.)

51. The detail that follows, supported by annex IV, shows, on the one hand, that the cost of producing the weapons can probably be estimated with fair accuracy, at least in countries with developed peaceful nuclear activities. On the other hand, experience has shown that the major part of the cost of a nuclear force is that of the delivery systems and, in particular, of the missiles, and these are liable to very large overruns and continuing costly development.

52. The indigenous development of a nuclear weapon capability is thus seen to demand not only major financial resources but very highly specialized human resources that are liable to be even more significant.

BASIC COSTS OF NUCLEAR WARHEADS

53. The three fissile materials suitable for use as nuclear explosives are uranium-235, plutonium-239 and uranium-233. Uranium-233 is still

rare, so its cost has not been considered here. A kilogramme of natural uranium contains seven grammes of uranium-235, while the main component is uranium-238. For use as a nuclear explosive the uranium-235 has to be separated and concentrated or "enriched" to 90-95 per cent of total uranium. The five nuclear weapons Powers have each established a capability for producing highly enriched uranium-235. So far as is known only one process for uranium-235 isotope separation has been put into large-scale use. It is known as the gaseous diffusion process and is applied to gaseous uranium-hexafluoride (UF_6). This process requires large and costly plants based on an advanced technology which has not been fully disclosed. The total cost of the three United States plants was around $2,300 million, and the annual operating costs were estimated at from $500 million to $600 million, resulting in a cost of $11,000 to $12,000 per kilogramme of weapons-grade uranium. Some twenty-five kilogrammes of this material would be required for the production of one nuclear warhead with a yield in the twenty-kiloton range. Uranium-235 is preferred over plutonium for the production of thermonuclear weapons (H-bombs).

54. Plutonium-239 results from exposing uranium-238 to neutrons in a nuclear reactor. It is estimated that some eight kilogrammes of 95 per cent plutonium-239 would be needed for a nuclear warhead yielding a twenty-kiloton explosion.

55. A complete plutonium-239 production complex would require plants for concentrating uranium ore, refining the uranium to high purity, and probably reducing it to metal ingot, and for fabricating reactor fuel, a nuclear reactor, a chemical plant for plutonium extraction and one for reducing plutonium to metal, together with numerous service facilities. For production complexes with capacities in the range of 8-160 kilogrammes of weapons-grade plutonium per year, the capital costs would be in the range of $22-$87 million, and the annual operating costs $5-$10 million, resulting in a cost of $900,000 per kilogramme of plutonium for the small complex and $120,000 per kilogramme for the larger complex over the ten-year programme.

56. Considering the high cost of the gaseous diffusion plant for uranium-235, it would seem that a country planning to make only a small number of nuclear warheads per year would go to the plutonium type. This is particularly so if it has an established activity in the peaceful uses of nuclear energy, since plutonium is produced as a by-product in most nuclear reactors.

DESIGNING, MANUFACTURING AND TESTING

57. The amount of published information relating to warhead assembly and testing is severely limited by military secrecy.

58. According to a Swedish study made for the purpose of this report the capital investments in a factory for assembling ten warheads

per year would be about $8 million and annual operating costs about $1 million.

59. According to the same Swedish study the total costs of testing one twenty-kiloton device underground would amount to $12 million, and the costs of testing four such devices would amount to $15 million.

COSTS FOR VARIOUS WARHEADS PRODUCTION PROGRAMMES

Plutonium warheads production programme

60. Based on the estimated cost figures given for plutonium production and warhead design, manufacturing and testing, the total estimated costs of a small programme (one twenty-kiloton warhead per year over ten years) and a moderate programme (ten twenty-kiloton warheads per year over ten years) are shown below in table 1. The small programme would cost $11 million per year, i.e., $11 million per warhead, whereas the moderate programme would cost $19 million per year, resulting in a warhead unit price of $1.9 million. If the small programme could be combined with plutonium production in a large power reactor, the annual costs might be reduced to $6 million and consequently the warhead unit costs to $6 million.

TABLE 1. ESTIMATED COSTS FOR VARIOUS PLUTONIUM-BASED WARHEAD PRODUCTION PROGRAMMES

(In $US millions)

	Small programme (10×20-kiloton devices over ten years)	*Moderate programme (100×20-kiloton devices over ten years)*
Fissile material	70.0	151.0
Design and manufacture	18.0	18.0
Testing	12.0	15.0
Storage, maintenance	4.0	4.0
TOTAL	104.0	188.0
Annual average	11.0	19.0
Cost per warhead	11.0	1.9

Production programme including thermonuclear warheads

61. The escalation of the total warheads production costs resulting from the construction and operation of a diffusion plant for enriching uranium-235 and the development and testing of thermonuclear weapons is well demonstrated by the French example shown in table 2. The gaseous diffusion plant was built after 1960.

Cost of delivery vehicles

62. Table 3 gives a summary of the reported procurement and operation costs for a variety of delivery vehicles, ranging from ele-

TABLE 2. COSTS OF TOTAL FRENCH NUCLEAR WARHEADS PROGRAMME
(In $US millions)

	Fissile material production	*Design and manufacture*	*Testing*	*Total*
To 1960	160	40	40	240
1960–1964	880	460	300	1,640
1965–1970				3,180
GRAND TOTAL	1,040 (to 1964)	500 (to 1964)	340 (to 1964)	5,060

mentary to sophisticated systems. The table indicates that the total delivery vehicle costs in most circumstances will be greater than the nuclear weapons costs.

63. The accuracy with which delivery vehicle costs were predicted has been notoriously poor. Heavy overruns of expenditures have been the rule rather than the exception and have been concurrent with lengthy delays in the projected time-tables. Many instances exist of the deployment of extremely costly but already obsolescent weapons systems, which were withdrawn a very short time after their initial deployment. Furthermore, while it is not always correct, it can be generally assumed that the accuracy of cost and time estimates for both the development and production of delivery vehicles is a function of prior related experience. Overruns are therefore more likely to be incurred when a country embarks on its first-generation development.

64. The time needed to develop a delivery system depends on the existing industrial base and related experience and would, in most cases, take at least ten years for reasonably industrialized nations. Costs can be spread over time, but peaks occur at certain points. Obsolescence and countermeasures costs are related to the time factor.

65. Monetary costs do not, by themselves, give a realistic picture of the necessary effort in terms of over-all resources. A sizable technological base is needed to create and maintain a force of delivery vehicles.

66. Included here are the necessary skilled workers, engineers, scientists and managers, fabricating facilities, experimental facilities, test ranges, etc. Even if major components can be purchased abroad, the delivery system must be integrated into a workable whole, and this process requires the skills of a number of qualified persons, which may even exceed the number needed for warhead production.

PROCUREMENT COSTS SUMMARY

Modest nuclear capacity

67. It will be assumed that a modest but significant nuclear armament would be represented by a force of from thirty to fifty jet bomber

TABLE 3. SUMMARY OF DELIVERY VEHICLE PROCUREMENT AND OPERATIONS COSTS
(Costs in $US millions)

System category	*System description*	*Procurement costs*	*Annual operating costs*
Aircraft, elementary	30–50 bombers (Canberra, B-57)	180	25
Missile, elementary	50 missiles in soft emplacement, 1,000-km range	440–540	5
	50 missiles in soft emplacement, 3,000-km range	800–900	10
	13 US Atlas squadrons (140 missiles)	4,900	2 (per missile)
Aircraft, medium-level	50–60 French Mirage IV bombers	940	100
	300 British V-bombers with air-to-surface missiles	1,800	120
Missile, medium-level	50 Minuteman I, in hard emplacements, 10,000-km range	1,250	5
	25 French SSBS in hard emplacements, 4,000-km range	700	Not available
	14 US Titan squadrons (140 missiles)	4,900	Not available
Aircraft, sophisticated	210 US FB-111 with SRAM air-to-surface missiles	2,200	340 (total to 1971)
Missile, sophisticated	3 French missile-launching nuclear submarines, each with 16 missiles of 3,000-km range	1,000	20
	41 US Polaris launching submarines, each with 16 missiles	13,000	Not available

aircraft (table 3), together with fifty medium-range missiles of the 3,000-kilometre range in soft emplacements and 100 plutonium warheads. The sum of the costs estimated above for such a system acquired and deployed over ten years would be at least $1,700 million, averaging $170 million per year.

Small, high-quality nuclear force

68. A Polish study has been made for the purpose of this report to estimate the costs of a small, high-quality nuclear force. A hypothetical programme comprising two stages each of five years' duration has been envisaged. By the end of the first stage (1968-1972) a nuclear force of from ten to fifteen bombers and from fifteen to twenty nuclear weapons would be established, and during the second stage (1973-1977) the force would be extended to include from twenty to thirty thermonuclear weapons, 100 intermediate range missiles and two missile-launching nuclear submarines. The total costs of such a programme based on domestic industry and resources would amount to $5,600 million, corresponding to an average annual cost of $560 million for ten years. This hypothetical programme could be considered as a scaled-down version of the French programme. The cost estimate is considerably lower than the expenditures in France and the United Kingdom. Both are in the course of establishing high-quality nuclear forces of moderate size. French costs for their military nuclear programme to 1969 have been estimated at $8,400 million, and the United Kingdom costs to 1969 are a similar amount. Annual outlays of $50 million were representative of the early French programme, but outlays later rose to as much as $1,000 million in a single year.

69. The actual annual costs of the nuclear forces in some countries are shown in table 4. The costs are also given relative to the annual defence budgets and the gross national product (GNP).

TABLE 4. ACTUAL COSTS OF NUCLEAR FORCES

Country	*Period of time*	*Total costs (in $US millions)*	*Annual costs as percentage of*	
			Military budget	*GNP*
France	1960-1964	2,400	13.0	0.7
	1965-1970	5,200	18.0	0.9
United Kingdom	1962-1963	480	10.0	0.7
	1965-1966	350	6.0	0.4
	1966-1967	300	5.0	0.3
USA	1962	13,200	26.4	2.4
	1963	12,100	23.3	2.1
	1964	11,200	21.1	1.8
	1965	8,200	16.8	1.3
	1966	8,200	14.6	1.2
	1967	8,400	12.1	1.2

70. Comparison of the figures given in table 4 should be made with caution, partly because they refer to countries at different stages of nuclear weapons development, and partly because the size of the respective nuclear forces is not known.

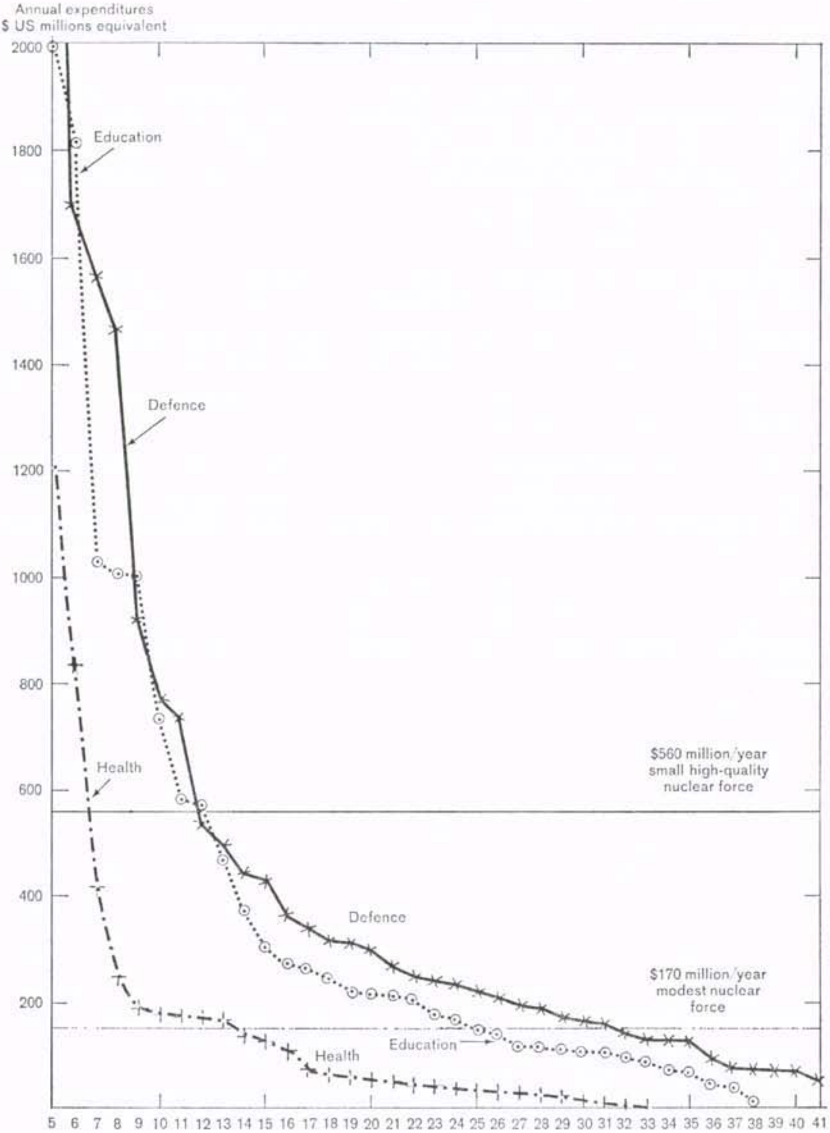
ECONOMIC IMPLICATIONS

71. What has been defined as a modest nuclear armament requires not only a ten-year programme costing the equivalent of $US 170 million per year but resources of special kinds and quality. The basic ingredients would be raw materials, a corps of skilled engineers and expert scientists and a modern industrial base. A study of the number of scientific and technical personnel required by a nation to build installations in which nuclear warheads could be produced on a continuous basis has estimated that approximately 1,300 engineers and 500 scientists would be needed. Sophisticated delivery systems are equally demanding of high-quality materials and skills. For production of the intermediate-range ballistic missiles, estimates suggest that manpower requirements for technical and skilled personnel would rise higher than those for nuclear weapons. To produce over ten years and deploy fifty such missiles, it is estimated that a peak labour force of 19,000 men directly applied would be needed, over 5,000 of them scientists and engineers with access to high-speed electronic computers. Skilled personnel would include physicists, aerodynamic, mechanical, and other engineers and large numbers of production workers, including machine operators and welders. The suggested fleet of fifty bombers would require a minimum of from 1 to 2 million man-hours of skilled and unskilled labour just to assemble. The design and development stage would absorb an additional 2 million or more engineering man-hours, which would involve highly skilled efforts in aerodynamics, stress analysis, design work and flight testing.

72. To compare the hypothetical nuclear armament costs with other major national expenditures, reference has been made to statistical information available to the United Nations and published in several editions of the *Statistical Yearbook*. At this time most of such information is available for the year 1964. Expenditures are always expressed in units of the national currency. The largest uncertainties in making comparisons arise when a variety of exchange rates are quoted for the currency under different circumstances and when currencies become unstable. Further differences arise because nations operate under different economic systems and because accounts are kept on differing bases. Because of all these differences it is possible to make only rough comparisons, such as illustrated in figure VIII.

73. Fifty countries which, on the basis of population and total expenditures, were seen to be the largest, were selected. Expenditures for 1964 on defence, education and health are reported in the United Nations *Statistical Yearbook, 1965* (United Nations publication, Sales No.: 66.XVII.1), tables 192 and 185, for most but not all of the fifty.

FIGURE VIII. COMPARISON OF HYPOTHETICAL NUCLEAR ARMAMENT EXPENDITURES WITH REPORTED NATIONAL EXPENDITURES ON DEFENCE, EDUCATION AND HEALTH



Number of countries reporting higher expenditures for 1964 (or 1963).

The numbers at the bottom of the graph representing countries relate to table 11, annex IV, page 73.

The graph in figure VIII shows these reported expenditures and the number of countries with that or a higher expenditure for each of the three fields, defence, education and health.

74. Horizontal lines are drawn corresponding to the two illustrative expenditures of $170 million (US equivalent) per year for a modest nuclear force, and of $560 million per year for a small high-quality force. The graph shows that these levels would represent a very large component of the total defence expenditure for all except about the eleven largest countries, that is, seven countries in addition to the existing nuclear weapons Powers included in the graph. About twenty countries have higher total defence expenditures than that for the modest nuclear armament of $170 million per year.

75. It thus appears that there are only about seven countries in the world, other than the five nuclear weapons Powers, that could contemplate an added expenditure of $170 million a year to develop a modest nuclear armament without reallocating a major part of their technical resources from constructive activities. For the small nuclear capability suggested, costing $560 million a year, only the seven appear capable of finding the necessary resources.

76. What may be derived correctly from the graph is an appreciation of the relative magnitude of the expenditure on a nuclear force compared with other government expenditures on defence, education and health. Any further deductions from the graph should be made with caution, for it must be remembered that accounts are not kept in the same way and rates of currency exchange vary. Moreover, what are reported are central and regional government expenditures, and in many countries education and health are to a considerable extent financed otherwise.

IMPLICATIONS OF EXPECTED GROWTH OF PLUTONIUM RESOURCES

77. There are two observations that we can make. First, that the cost of development of simple nuclear warheads is progressively decreasing as the technology involved is increasingly becoming public knowledge, and a new country can avoid the unprofitable directions which the countries that pioneered had to discover through costly experience. Second, that the large-scale development of nuclear power projects, resulting from a break-through in capital as well as operating costs, compared to conventional power stations, will make available a very large capacity of potential producers of weapons-grade plutonium. It is estimated that by 1980 there would be in the world more than 3×10^5 megawatts of nuclear power production. This would involve the production of plutonium sufficient for thousands of bombs each year. This illustrates the enormity of the problem that the world faces, a problem coupled with the peaceful application of atomic energy.

III. SECURITY IMPLICATIONS OF THE ACQUISITION AND FURTHER DEVELOPMENT OF NUCLEAR WEAPONS

INTRODUCTION

78. In concluding this report, it is necessary to discuss the implications to security of the acquisition and further development of nuclear weapons. The task is not an easy one. This particular issue, whether viewed in a national or an international context, constitutes one of the major subjects of present-day political and strategic debate. It is one which is perhaps best approached historically.

HISTORY OF NUCLEAR WEAPONS

79. As recalled in section I, it was in 1945, at the end of the Second World War, that the world learnt that a nuclear weapon of mass destruction had been developed by the United States of America. In the realization that this development could imply dire consequences for mankind, the unanimous first resolution of the General Assembly of the United Nations was that atomic energy should be placed under international control and that atomic weapons should be eliminated from national arsenals. The attempt failed. A nuclear arms race then began. In 1949, the Union of Soviet Socialist Republics revealed that it, too, possessed nuclear weapons. The race acquired new dimensions when both Powers developed the H-bomb with an explosive power of megatons and when it was also demonstrated that nuclear warheads could be delivered accurately not only by aircraft but, over practically limitless ranges, by means of intercontinental rockets. From this grew the realization that were one side to attack with nuclear weapons, the other could instantly retaliate in kind, whether or not there were any differences in the numbers of bombs they possessed. So it was that the concept of strategic nuclear deterrence evolved. The reality of this concept is indicated by the fact that whatever the political conflicts between the two super Powers over the past fifteen years, they have not engaged in any direct military conflict. Fear of the disastrous consequences of the explosion of even a few nuclear bombs has so far contributed towards inhibiting any action which might have triggered their use.

80. The effort to maintain a state of nuclear deterrence has demanded the expenditure of vast resources and, paradoxically, far from increasing the sense of security, has at times engendered a sense of insecurity. The opposing sides have taken, and continue to take, major

steps to assure themselves that their nuclear warheads and delivery vehicles are proof against whatever countermeasures might be undertaken by the other side. These countermeasures are essentially designed to increase the chances of a nuclear armoury surviving a pre-emptive nuclear assault by the other side and of nuclear weapons being able to penetrate whatever defences the other might deploy. The reciprocal technological development and sophistication of nuclear warheads and their associated weapons systems which thus results constitute a spiralling nuclear arms race. Short of mutual agreement, it is a race which has no end, and one which leads not to a uniform state of security but, as has been said, to phases of major insecurity which alternate with periods in which relative security seems assured. The pace of this race cannot be expected to slow down until concrete steps are taken which lead to disarmament and which promote the security of all nations.

81. The United Kingdom, which had been associated with the United States during the Second World War in the early development of nuclear weapons, subsequently developed, on its own, a smaller nuclear armoury, and, at the start, delivery systems as well. Canada, which had co-operated with the United Kingdom during the war in the development of nuclear technology, decided not to embark on the manufacture of nuclear weapons. On the other hand, France, some of whose scientists had also taken part with the United Kingdom and Canada in the wartime collaborative effort in nuclear technology, began the development of its own nuclear weapons and delivery vehicles in the 1950s. The People's Republic of China has recently become the fifth State to follow the same course. The exact number of nuclear warheads which may now exist in the world is not known, but it is quite certain that the arms race between the United States and the Union of Soviet Socialist Republics alone has resulted in the production of weapons whose cumulative destructive power is more than sufficient to eliminate all mankind.

The current prospect

82. So far as international security is concerned, it is highly probable that any further increase in the number of nuclear weapons States or any further elaboration of existing nuclear arsenals would lead to greater tension and greater instability in the world at large. Both these aspects of the nuclear arms race are significant to world peace. The mounting concern about the spread and development of nuclear weapons is a clear manifestation of the fear which now besets the world. Additional nuclear Powers accentuating regional tensions could only add to the complexity of the problem of assuring peace. Furthermore, it is impossible to deny the proposition that the danger of nuclear war breaking out through accident or miscalculation becomes greater, the larger the number of countries which deploy such weapons and the larger the stockpiles and the more diversified the weapons they hold. If a nuclear conflict were to erupt, however it started, not a single State could feel itself secure. Even if a State were not subjected to direct attack, and even

if it should not experience any immediate consequences of such an attack, it could nevertheless suffer as a result of later radio-active fall-out. It was largely because the whole world was concerned about the fall-out from the nuclear tests of the 1950s and early 1960s that the principal international agreement so far concluded to limit the spread of nuclear weapons—the partial ban on nuclear tests—was signed in 1963.

83. Every one of the five nations known to have nuclear weapons describes its motives for developing a nuclear arsenal as purely tactical-defensive and/or defensive by deterrence. Not one would claim that it had developed the weapons because of their value as weapons of offence. But the transformations which have occurred over the past twenty years in the balance of strategic power in the world, as well as what is implied by nuclear war, have produced a vastly different scene from the one which existed at the start of the Second World War. It is also plain from the history of the past twenty years that the possession of a nuclear arsenal does not, and cannot, signify the same thing to different countries, either in terms of military power or of political security. Correspondingly, it stands to reason that countries which have not embarked upon the development of nuclear weapons will have refrained from so doing because of a variety of differing views about the advantages and disadvantages of such a step.

84. The possibility of an increase in the number of countries acquiring a nuclear arsenal is attributable to different sets of motives. In some quarters the fact that the existing nuclear weapons Powers have so far failed to reach agreement either about stopping the further development or of freezing or reducing their own nuclear arsenals is regarded as an argument for the acquisition of nuclear weapons by other nations. In searching for greater security, some may also believe that if a state of mutual deterrence has been generated between the existing nuclear weapons Powers, a corresponding situation could be created between any other Powers who already possess the industrial and technological background necessary to make bombs and, in future, between countries which do not as yet do so. But against such views, it is worth noting that nowhere has the development of nuclear weapons made it possible to dispense either with troops on the ground or with conventional arms. Any new country which embarked on the production of nuclear weapons would soon find that it had entered a new arms race without having provided itself with the option of abandoning the old. Thus, the burden of an arms race with conventional weapons is compounded as soon as a nation embarks upon the path of acquiring nuclear weapons. Moreover, the insecurity which would be brought about by entering the nuclear arms race would make it imperative to improve continuously the sophistication of the nuclear weapons and their delivery systems, as well as measures for providing an early warning of an impending attack. The nuclear arms race demands immense technological and other resources and, of itself, creates conditions under which the economic progress of a nation could stagnate. The internal insecurity engendered by the diversion of resources can be

quite as serious as the external threat to the nation. Again, the acquisition by any nation of nuclear weapons could also trigger a change in its international relations. Non-nuclear neighbours could be tempted to acquire nuclear weapons, or they might perhaps undertake immediate preventive military action. Having nuclear weapons on one's own territory might bring with it the penalty of becoming a direct target for nuclear attack. A nuclear capability intended to deter or offset another on a bilateral basis would be confronted with changing alliances and changing balances of power. What had been intended to be a military answer to one set of threats might then appear inadequate, subject to quick neutralization or elimination in the event of an outbreak of nuclear hostilities. Similarily, the existing nuclear Powers might react by countermeasures and/or attempts to strengthen their own position in the region and thereby intensify their own arms race. Nuclear weapons nations are also faced with the problems of establishing systems of control of nuclear weapons within their own borders. Not only must there be protection against misuse; the tensions which would exist if serious civil strife were to occur in a nation that possessed nuclear weapons would be greatly intensified. If these problems are not adequately solved, there are added risks to the security of that nation and to the world as a whole. It is presumably for reasons such as these that the emergence of a fourth and then a fifth nuclear weapons Power has not stimulated further proliferation over the past three years. But the situation remains far from stable. Even the world-wide concern about proliferation, which the major Powers clearly share, has not as yet led to any measures of nuclear disarmament.

85. Clearly any arms race absorbs resources which might otherwise be used to improve standards of living. The struggle to improve living conditions is most effectively pursued when advanced technological products are freely exchanged between countries. This process is hindered by the mutual fears and suspicions associated with an arms race. The peaceful uses of atomic energy, now still on a small scale, are expected in the years ahead to become of major significance to world prosperity. Most nations are member States of the International Atomic Energy Agency, which was established "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world". In recent years they have agreed about the need to develop a system of safeguards involving inspections to assure that materials and facilities acquired to assist a programme of peaceful uses are not diverted to any military purpose. In no case does the Agency assist any trade leading to nuclear weapons. The achievement of the Agency's mission is of considerable importance to the peaceful development of the whole world.

THE ISSUE OF TACTICAL WEAPONS

86. A second motive additional to the search for "security through deterrence" which might encourage proliferation is the view that nuclear

weapons constitute a form of armament superior to conventional weapons in field warfare. Some military commentators assume that armies could use such weapons against each other within the zone of contact of a battle area. If only one side to a dispute possessed and deployed nuclear weapons and was known to be ready to use them so as to achieve its objectives, regardless of any international repercussions, the possibility exists that it might gain an advantage either from the threat of using them—that is to say, the threat itself would deter the military actions of its opponent—or from the results of their actual use. It is also just credible that if both sides were to possess such weapons, whatever their actual nature, and one, two or even a few were to be exploded, the two sides would disengage because of the realization, having observed the consequences of their use, that the conflict might escalate into an uncontrollable conflagration. These things are possible. But the contrary is far more likely. It is hardly likely that a non-nuclear-weapons country, living in a state of hostility with a neighbour, could start to furnish itself with a nuclear arsenal without either driving its neighbour to do the same or to seek protection in some form or other, explicit or implicit, from an existing nuclear weapons Power or Powers. Equally, if in the pursuit of its political objectives, one of two sides, both of which possessed and deployed nuclear weapons, were to have the will to initiate the use of its weapons, it is difficult to see how a nuclear engagement could be stopped once it had started. The speed of military reaction and experience of past military operations do not encourage any opposite conclusion. From what has been said in section I of the report, it is clear that, given that both sides to a conflict deploy nuclear weapons, it is highly debatable whether there are any circumstances of land warfare in which such weapons could be used as battlefield weapons or, if they were so used, would confer any military advantage to either side in the zone of contact. Whatever significance can be attributed to tactical nuclear weapons is to be found essentially in the concept of deterrence.

NUCLEAR WEAPONS IN THE POLITICAL CONTEXT

87. The third argument which is sometimes advanced in favour of the acquisition of nuclear weapons is that doing so promotes political independence, enhances national prestige and thus a country's influence on the international scene. A contrary view is that the influence of certain Powers in international affairs would be the same whether or not they possessed nuclear weapons. The issue of prestige is equally debatable. Undoubtedly there may for a short time be some imponderable element of prestige in the manifestation of the technological prowess which is implied by the development of nuclear weapons. But this prestige is a mixed blessing and could rapidly generate those deleterious reactions on the part of neighbouring States to which reference has been made in a preceding paragraph.

88. When one asks whether or not the acquisition and further development of nuclear weapons increases security, one thus ends up

with two very simple questions. The first is what, in fact, have nuclear weapons contributed so far to military power? In so far as this question can be answered, the reply can only be that while the nuclear weapons Powers have never suffered aggression on their own territories, and while the state of mutual deterrence which prevails between the two super Powers has helped to avert any head-on conflict between them and has indeed imposed a new kind of restraint in their political actions with respect to each other, it has not made it possible for either to reduce its military expenditures in general or to neglect the effectiveness of its conventional armoury in particular. In a smaller way, the same conclusion applies to both the United Kingdom and France.

89. At the same time, profound limitations clearly exist in the possible use of these weapons. The consequences of their employment either in all-out war or in field warfare would be so disastrous to both sides that it is very difficult to conceive of circumstances in which they could be used. Where two sides possess such weapons, it is totally unrealistic to suppose that one could use them in a military conflict without provoking retaliation by the other. Once retaliation had occurred, it is also difficult to suppose that a nuclear conflict would not escalate in intensity. The possibility that it might not cannot be excluded; but the chances are much greater that it would. The situation might, of course, be totally different if only one side to a localized conflict possessed nuclear weapons. But here one needs to observe that views about the value of nuclear weapons as actual instruments of military power vary just as much in States that do not possess nuclear weapons as in those that do. For example, over the past twenty years non-nuclear-weapons countries have not been deterred from engaging in battle on or near their own ground with States possessing nuclear weapons. In these encounters, the latter have not found that their possession of nuclear weapons and their deployment in the theatre of operations has made the course of conventional war any easier. Indeed, since the end of the Second World War, no nuclear weapons State has been able to derive any immediate military advantage from the possession of nuclear weapons, let alone use them to gain an easy victory.

90. The second question is in what way, if at all, does the possession of nuclear weapons strengthen power; or what quality, if any, do such weapons impart to it? This is a much more difficult question. National security and political power are tenuous concepts. There are countries which enjoy a high measure of both, regardless of the fact that they do not count among the military Powers of the world. Equally, while the nuclear Powers have at times been able to exercise immense political power and economic influence in world affairs, there have also been moments in recent history where this has not been so, regardless of the great nuclear forces of which they dispose. Correspondingly, the possession of nuclear forces does not necessarily prevent a decline in political influence. Were the acquisition and maintenance of a nuclear arsenal to impose a major economic and technological burden on a

country, it is possible that possession of such an arsenal would be associated with a reduction, and not with an increase, in both the national security and political influence of the country concerned.

CONCLUSION

91. Since the sense of insecurity on the part of nations is the cause of the arms race, which in turn enhances that very insecurity, and in so far as nuclear armaments are the end of a spectrum which begins with conventional weapons, the problem of reversing the trend of a rapidly worsening world situation calls for a basic reappraisal of all interrelated factors. The solution of the problem of ensuring security cannot be found in an increase in the number of States possessing nuclear weapons or, indeed, in the retention of nuclear weapons by the Powers currently possessing them. An agreement to prevent the spread of nuclear weapons as recommended by the United Nations, freely negotiated and genuinely observed, would therefore be a powerful step in the right direction, as would also an agreement on the reduction of existing nuclear arsenals. Security for all countries of the world must be sought through the elimination of all stockpiles of nuclear weapons and the banning of their use, by way of general and complete disarmament.

92. A comprehensive test ban treaty, prohibiting the underground testing of nuclear devices, would also contribute to the objectives of non-proliferation and would clearly help to slow down the nuclear arms race. So would effective measures safeguarding the security of non-nuclear countries. Nuclear-weapon-free zones additional to those of Antarctica and Latin America, covering the maximum geographical extent possible and taking into account other measures of arms control and disarmament, would equally be of major assistance.

93. These measures are mentioned neither to argue the case for them nor to set them in any order of priority. What the analysis of the whole problem shows is that any one of them, or any combination of them, could help inhibit the further multiplication of nuclear weapons Powers or the further elaboration of existing nuclear arsenals and so help to ensure national and world security. But it must be realized that these measures of arms limitation, however desirable, cannot of themselves eliminate the threat of nuclear conflict. They should be regarded not as ends sufficient in themselves but only as measures which could lead to the reduction of the level of nuclear armaments and the lessening of tension in the world and the eventual elimination of nuclear armaments. All countries have a clear interest in the evolution of a world which allows of peaceful and stable coexistence. Non-nuclear weapon countries, as well as those which possess nuclear weapons, need to work in concert, creating conditions in which there should be free access to materials, equipment and information for achieving all the peaceful benefits of atomic energy, and for promoting international security.

94. This report gives the bare outline of the disasters which could be associated with the use of nuclear weapons. It discusses the nature and variety of the economic burden they impose. And it unhesitatingly concludes from the considerations that have been set out that whatever the path to national and international security in the future, it is certainly not to be found in the further spread and elaboration of nuclear weapons. The threat of the immeasurable disaster which could befall mankind were nuclear war ever to erupt, whether by miscalculation or by mad intent, is so real that informed people the world over understandably become impatient for measures of disarmament additional to the few measures of arms limitation that have already been agreed to—the limited ban on testing, the prohibition of nuclear weapons in outer space, and the nuclear-free zone of Latin America. International agreement against the further proliferation of nuclear weapons and agreements on measures of arms control and disarmament will promote the security of all countries. The United Nations has the overriding responsibility in this field. The more effective it becomes in action, the more powerful its authority, the greater becomes the assurance for man's future. And the longer the world waits, the more nuclear arsenals grow, the greater and more difficult becomes the eventual task.

Annex I

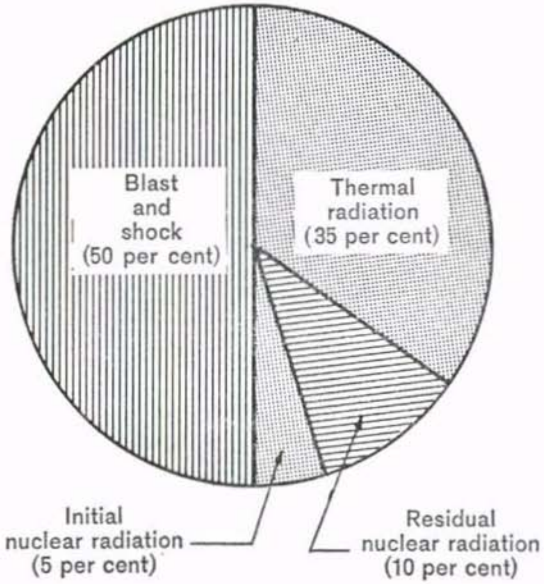
GENERAL CHARACTERISTICS OF NUCLEAR EXPLOSIONS

1. The yield of a nuclear weapon is expressed in terms of the energy released when it is exploded, compared with the energy liberated by the explosion of the chemical explosive trinitrotoluene (TNT). The biggest bombs ever made from conventional explosive contained the equivalent of about 10 tons of TNT. A one-kiloton nuclear weapon produces the same amount of energy as 1,000 tons of TNT. Correspondingly, a one-megaton weapon would release energy equivalent to 1 million tons (or 1,000 kilotons) of TNT. Using powerful rockets, any such weapons could be delivered, in less than an hour, between any two points on earth. Nuclear explosions of more than fifty megatons have already occurred and even larger ones are possible, since there appears to be no upper limit to the yield of a nuclear weapon except in terms of practicable size and weight.

IN THE ATMOSPHERE

2. When a nuclear weapon is exploded in the atmosphere, 50 per cent of its total energy is released as blast and shock, 35 per cent as thermal radiation and 15 per cent as nuclear radiation (see figure IX). These proportions vary according to whether the explosion is carried out in the atmosphere, or at altitudes greater than 100,000 feet, or underground. At high altitudes, the proportion of

FIGURE IX. DISTRIBUTION OF ENERGY IN AN AIR-BURST OF A FISSION WEAPON AT AN ALTITUDE OF LESS THAN 100,000 FEET



energy converted into blast would be decreased while the proportion of intense thermal radiation would be increased; in the underground case, no thermal radiation would escape. A nuclear explosion thus differs characteristically from an explosion caused by conventional explosives, not only in that its explosive power is several orders of magnitude greater than for a conventional explosive of the same mass, but also in so far as it results in effects from thermal and nuclear radiation.

3. The blast effects and associated overpressures from any particular nuclear explosion depend on the power of the weapon exploded and the altitude at which the explosion occurs (tables 1 and 2). The thermal radiation travels through the atmosphere at the speed of light and to distances depending on visibility through the atmosphere at the time of the explosion (see figure X). It can be of sufficient intensity from a one-megaton explosion on a fairly clear day to cause moderately severe burns on exposed skin over a radius of twenty kilometres (table 3). The heat might be felt as far away as 120 km. Serious fires could be started in cities and forests, possibly leading to fire-storms, i.e., gigantic fires in which air is sucked into the centre of the burning region to create a flaming funnel which destroys everything within it. For atmospheric explosions, having an energy greater than one megaton, these distances would be even greater. It has been estimated that on a clear day, a ten-megaton bomb exploded at an altitude of fifty kilometres would scorch the earth's surface over an area with a radius of some seventy kilometres. The thermal energy received per unit area, at a specified distance from a nuclear explosion, is usually expressed in calories per square centimetre.

FIGURE X. TOTAL THERMAL ENERGY DELIVERED, AS A FUNCTION OF DISTANCE FROM A 20-KILOTON NUCLEAR BOMB, FOR DIFFERENT ATMOSPHERIC VISIBILITIES

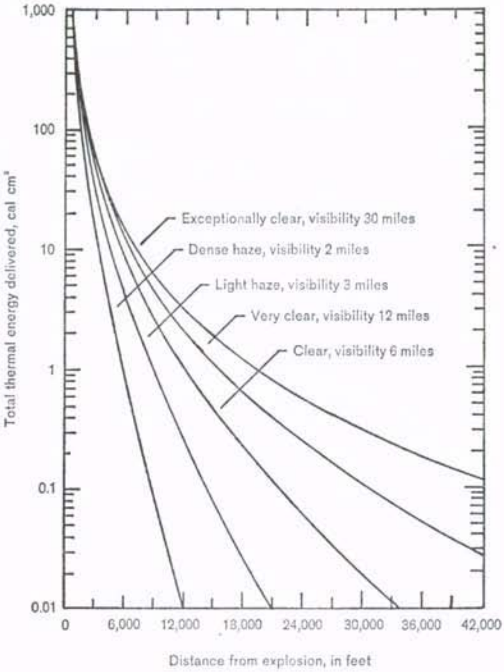
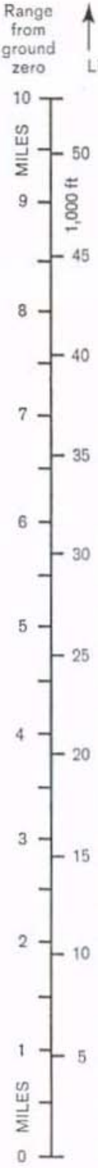


TABLE 1. DAMAGE RANGES FOR 20-KILOTON TYPICAL AIR-BURST AT HEIGHT OF ABOUT 600 METRES

Peak wind velocity (mph)	Positive phase duration (sec)	Peak dynamic pressure (psi)	Peak overpressure (psi)	Range from ground zero MILES	1,000 ft	
					↑	Light damage to window frames and doors, moderate plaster damage out to about 4 miles; glass breakage possible out to 8 miles
				2		
70	0.95	0.09	2.0		10	
				1.8		Fine kindling fuels: ignited
79	0.94	0.12	2.3		9	Wood-frame buildings: moderate damage Smoke stacks: slight damage
				1.6		
93	0.92	0.17	2.7		8	
				1.4		
112	0.90	0.27	3.2		7	Wood-frame buildings: severe damage Radio and TV transmitting towers: moderate damage Wall-bearing, brick building (apartment house type): moderate damage
				1.2		
139	0.86	0.42	4.2		6	
						Wall-bearing, brick buildings (apartment house type): severe damage
				1.0		Telephone and power lines: limit of significant damage
190	0.80	0.80	6.0		5	Multi-story, wall-bearing buildings (monumental type): moderate damage Light steel-frame, industrial buildings: moderate damage
				0.8		
291	0.72	1.50	10.0		4	
						Multi-story, wall-bearing buildings (monumental type): severe damage Light steel-frame industrial buildings: severe damage
				0.6		Highway and RR truss bridges: moderate damage
431	0.63	3.90	16.3		3	Multi-story, steel-frame building (office type): severe damage Transportation vehicles: moderate damage
				0.4		Multi-story, blast-resistant designed, reinforced-concrete building: moderate damage
459	0.54	7.60	32.5		2	Multi-story, reinforced-concrete, frame building (office type): severe damage Multi-story, blast-resistant designed, reinforced-concrete buildings: severe damage
				0.2		All other (above ground) structures: severely damaged or destroyed
260	0.44	3.70	30.0		1	
					0	Ground zero for 20 kiloton air burst

TABLE 2. DAMAGE RANGES FOR 1-MEGATON TYPICAL AIR-BURST AT HEIGHT OF ABOUT 2,000 METRES

Peak wind velocity (mph)	Positive phase duration (sec)	Peak dynamic pressure (psi)	Peak over-pressure (psi)	Range from ground zero (1,000 ft)
44	3.45	0.036	1.2	50
51	3.45	0.049	1.4	45
60	3.44	0.072	1.7	40
72	3.43	0.11	2.1	35
98	3.40	0.16	2.6	30
117	3.24	0.28	3.5	25
177	3.02	0.60	5.5	20
278	2.69	1.40	9.4	15
464	2.25	6.22	10.0	10
307	1.75	3.60	27.0	5



Light damage to window frames and doors, moderate plaster damage out to about 15 miles; glass breakage possible out to 30 miles

Fine kindling fuels: ignited

Smokestacks: slight damage

Wood-frame buildings: moderate damage

Radio and TV transmitting towers: moderate damage

Wood-frame buildings: severe damage

Telephone and power lines: limit of significant damage

Wall-bearing, brick buildings (apartment house type): moderate damage

Wall-bearing, brick buildings (apartment house type): severe damage

Light steel-frame, industrial buildings: moderate damage

Light steel-frame, industrial buildings: severe damage

Multi-story, wall-bearing buildings (monumental type): moderate damage

Multi-story, wall-bearing buildings (monumental type): severe damage

Highway and RR truss bridges: moderate damage

Multi-story, steel-frame building (office type): severe damage

Transportation vehicles: moderate damage

Multi-story, reinforced-concrete frame buildings (office type): severe damage

Multi-story, blast-resistant designed, reinforced-concrete buildings: moderate

Multi-story, blast-resistant designed, reinforced-concrete buildings: severe

All other (above ground) structures: severely damaged or destroyed

Ground zero for 1 megaton air burst

TABLE 3. RANGES, IN KILOMETRES FROM GROUND-ZERO, AT WHICH FIRST- AND SECOND-DEGREE BURNS WOULD BE INFLICTED BY EXPLOSIONS OF VARIOUS MAGNITUDES IN THE ATMOSPHERE*

	Distance in km from effective explosion				
Degree of burn	*1 kt*	*10 kt*	*100 kt*	*1 Mt*	*10 Mt*
First-degree burn (reddening of skin)	1.12	3	8.5	22.4	48
Second-degree burn (blistering of skin)	0.8	2.4	6.4	18	38.4

* In the case of surface explosions, the corresponding distances would be approximately ⅘ those for an aerial explosion of the same effectiveness.

4. Figure XI shows the area over which blast and thermal radiation effects would occur for typical ten-kiloton, one-megaton and ten-megaton explosions in the atmosphere. Within the circle in which overpressure amounts to 0.35 kg/cm^2 most normal buildings would be completely destroyed. For blast overpressure of 0.07 kg/cm^2 window frames, doors and walls would be only slightly damaged. Within the central zone of heavy damage there would be great danger of fires and individuals would be exposed to effects of nuclear and thermal radiation as well as blast.

INITIAL NUCLEAR RADIATION

5. The nuclear radiation from a nuclear explosion, occurring in the atmosphere, may be further considered as consisting of one third initial radiation, i.e., produced within a minute or so of the explosion, and two thirds residual or delayed nuclear radiation, i.e., emitted over a much longer period of time. The initial radiation may cause radiation sickness or death in human beings, depending on the dose of radiation received (table 4). A radiation dose of 100 rads[a] does not usually have harmful consequences for an exposed organism. A dose of 200 rads may produce some blood changes while a dose of 1,000 rads will cause illness within four hours and death within two or three weeks. Doses of 400 to 500 rads will cause radiation sickness and a 50 per cent expectation of death. These dose estimates apply to acute gamma[b] radiation; the same effects would be produced by lower doses of neutrons (see also table 5).

6. The initial nuclear radiation from an explosion in the atmosphere also travels a long way in air, although the intensity falls off fairly rapidly with increasing distance from the explosion. Unlike thermal radiation, nuclear radiation passes easily through most physical barriers. Heavy layers of materials are needed to reduce the intensity of nuclear radiation to harmless proportions; e.g., at a distance of 1.5 kilometres from a one-megaton weapon, burst in the atmosphere, an individual would need the protection of about 30 cm of steel or 130 cm of concrete to be relatively safe from the effects of initial nuclear radiation. On the other hand, any opaque object such as buildings or protective clothing interposed between the nuclear explosion and exposed skin would provide protection against thermal radiation. This would remain true even if the building were subsequently destroyed by blast, since the main thermal radiation would have passed before the arrival of the blast wave.

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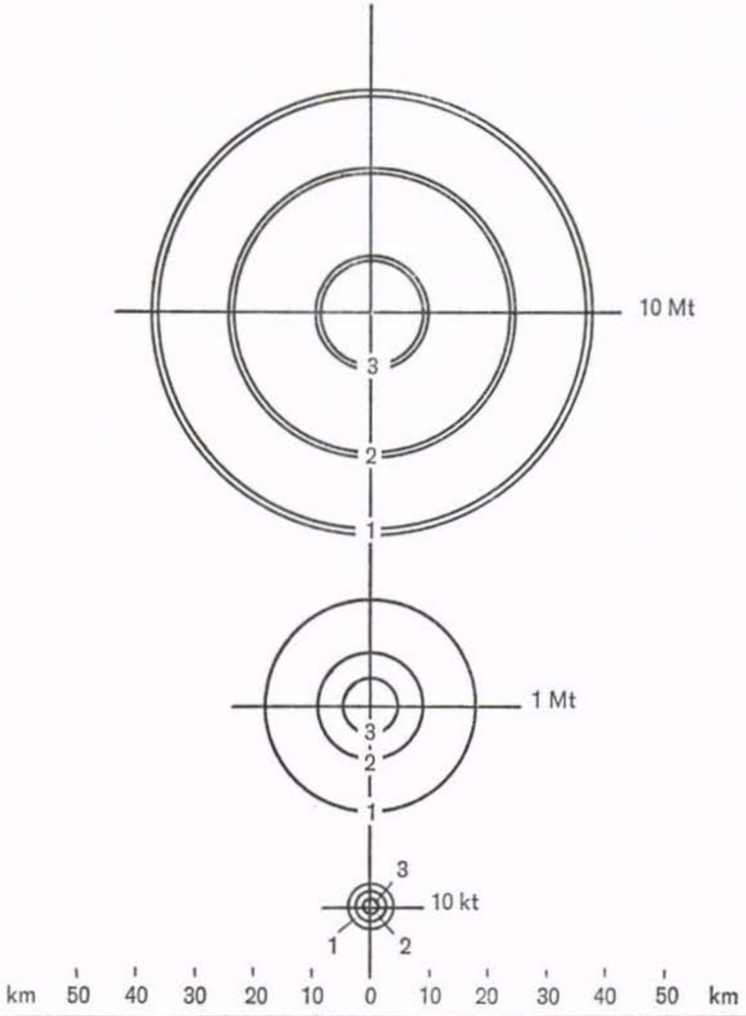
[a] Rad: A unit of absorbed dose of radiation; it represents the absorption of 100 ergs of nuclear (or ionizing) radiation per gramme of the absorbing material or tissue. An erg is a unit of work. It is the work done when a unit force of one dyne moves a body through one centimetre in the direction of action of the force.

[b] Gamma rays (or radiations) are electromagnetic radiations of high energy originating in atomic nuclei and accompanying many nuclear reactions, for example, fission and radio-activity.

TABLE 4. SUMMARY OF CLINICAL EFFECTS OF ACUTE IONIZING RADIATION DOSES

Range	0 to 100 rads – subclinical range	100 to 1,000 rads – therapeutic range (i.e., range in which therapy may be effective)			Over 1,000 rads – lethal range	
		100 to 200 rads	200 to 600 rads	600 to 1,000 rads	1,000 to 5,000 rads	Over 5,000 rads
		Clinical surveillance	Therapy effective	Therapy promising	Therapy palliative	
Incidence of vomiting	None	100 rads: 5 per cent 200 rads: 50 per cent	300 rads: 100 per cent	100 per cent	100 per cent	
Delay time	–	3 hours	2 hours	1 hour	30 minutes	
Leading organ	None	Haematopoietic tissue			Gastrointestinal tract	Central nervous system
Characteristic signs	None	Moderate leukopenia	Severe leukopenia; purpura; haemorrhage; infection; epilation above 300 rads		Diarrhoea; fever; disturbance of electrolyte balance	Convulsions; tremor; ataxia; lethargy
Critical period post-exposure	–	–	4 to 6 weeks		5 to 14 days	1 to 48 hours
Therapy	Reassurance	Reassurance; haematologic surveillance	Blood transfusion; antibiotics	Consider bone marrow transplantation	Maintenance of electrolyte balance	Sedatives
Prognosis	Excellent	Excellent	Good	Guarded	Hopeless	
Convalescent period	None	Several weeks	1 to 12 months	Long	–	
Incidence of death	None	None	0 to 80 per cent (variable)	80 to 100 per cent (variable)	90 to 100 per cent	
Death occurs within	–	–	2 months		2 weeks	2 days
Cause of death	–	–	Haemorrhage; infection		Circulatory collapse	Respiratory failure; brain oedema

FIGURE XI. ENVIRONMENTAL VARIATIONS DUE TO BLAST AND THERMAL RADIATION FOR 10 KT, 1-MT AND 10-MT EXPLOSIONS IN THE ATMOSPHERE



No	Effects	10 kt		1 Mt		10 Mt	
		Range (km)	Area (km^2)	Range (km)	Area (km^2)	Range (km)	Area (km^2)
1	Second degree burns..,	2.4	18.1	18	1018	38.4	4362
2	Overpressure 0.07 kG/cm^2	1.6	8.0	8.8	243	19.2	1158
3	Overpressure 0.35 kG/cm^2	1.2	4.5	4.5	63.6	14.7	680

TABLE 5. RANGES, IN KILOMETRES FROM GROUND-ZERO, WITHIN WHICH AN ATMOSPHERIC EXPLOSION WILL PRODUCE GIVEN DOSES OF INITIAL NUCLEAR RADIATION*

	1 kt	*10 kt*	*100 kt*	*1 Mt*	*10 Mt*
Radiation dose					
100 rads	1.12	1.6	2.1	2.9	3.8
500 rads	0.96	1.3	1.8	2.4	3.4
1,000 rads	0.8	1.12	1.6	2.24	3.2

* Distances for corresponding radiation doses would be reduced in the case of surface explosions.

RESIDUAL NUCLEAR RADIATION (FALL-OUT)

7. Residual or delayed radiation[e] arises almost entirely from the radioactivity of the debris left by the explosion. The proportion of this radiation may vary according to the type of nuclear weapon exploded. Meteorological and gravitational forces cause the bomb debris to be spread widely through the atmosphere over the countryside. The heavier particles fall close to the scene of the explosion, descending like a mild sand-storm, while the lighter particles are carried downwind. Both the heavy and light particles contain fused fission products and are highly radio-active; they constitute "fall-out" containing some fission products which remain dangerously radio-active for a relatively short period of time and some which will remain dangerously radio-active for many years. The former category contributes most of the external radiation after the initial burst; it also contributes to internal radiation through iodine-131 which when absorbed in the body is concentrated in the thyroid. In the second (long-lived) category, strontium-90 and caesium-137 are the most important fission products leading to radioactive contamination of human diets.

8. Relatively local fall-out may contaminate very extensive areas, depending on the size of the explosion, the height at which the explosion takes place, the wind pattern in the area at the time of the explosion and rain-out through the atmosphere (figure XII). Such an area may be of the order of some fifty square kilometres for a twenty-kiloton explosion, near the surface of the earth. In this case the debris would be largely confined to the lower atmosphere and about half of it would be removed, chiefly by rainfall, in a period of about three or four weeks, although some of the particles might circle the earth one or more times before being deposited. For an explosion of say ten megatons at the surface of the earth, intense local fall-out might extend as far as 500-600 km from the point of the explosion. If such an explosion occurred well above the surface of the earth, a considerable fraction of the debris would be carried into the stratosphere and, in these circumstances, some debris would require months or even years to return to earth. By that time a large proportion of the radio-active atoms produced by the explosion would have decayed.

9. In one particular incident, when a fifteen-megaton device was detonated in a nuclear test on a coral island, the resulting fall-out seriously contaminated an elongated area extending approximately 530 km downwind and varying in width up to nearly 100 km. In addition, there was a severely contaminated region upwind extending some thirty kilometres from the point of detonation. A total area of some 18,000 sq. km. was contaminated to such an extent that survival would

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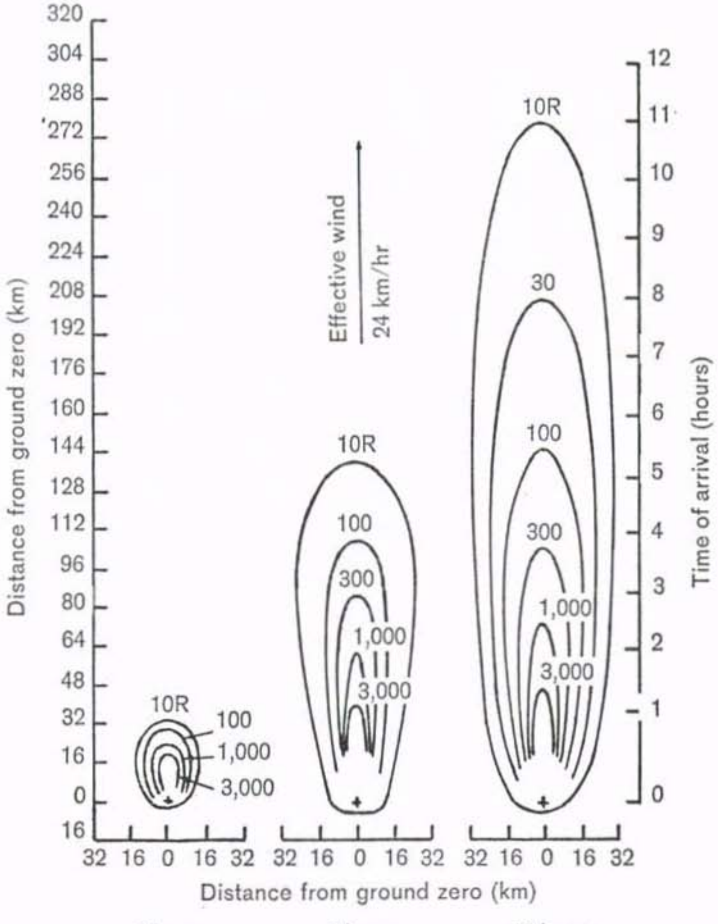
[e] Some delayed radiation may arise from radio-activity produced in materials in soil or structures as a result of nuclear reactions, following the capture of neutrons in such materials, after a nuclear explosion. This is known as induced XIII shows the estimated exposures that would have been received by individuals, radio-activity.

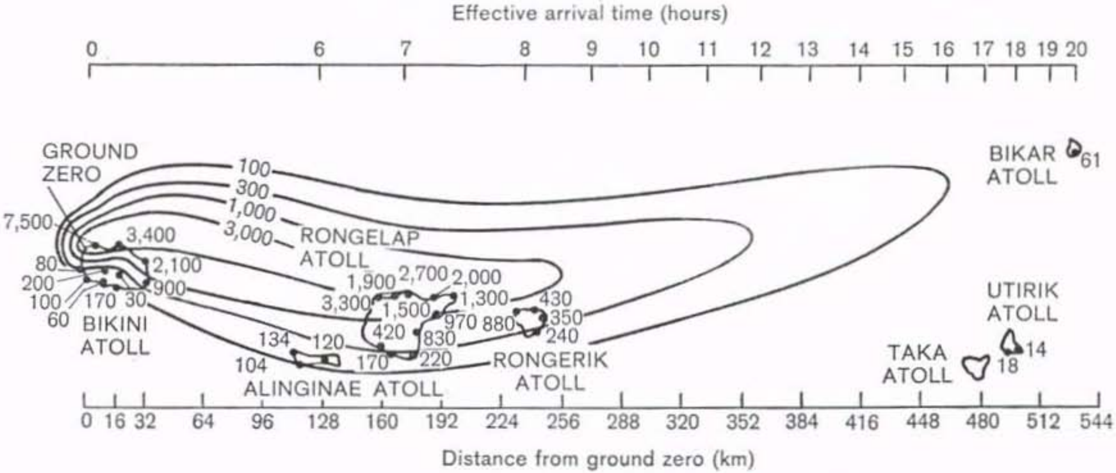
Figure XII. Total-exposure contours from early fall-out at 1, 6 and 18 hours after surface-burst with 1-megaton fission yield (24 km/hr effective wind speed). Exposures in roentgens (R). One roentgen of gamma radiation corresponds to the absorption of about 87 ergs per gramme of air



have depended on evacuation of the area or taking protective measures. Figure remaining unprotected in the open, at various locations ninety-six hours following the explosion. Since an exposure of 700 rads spread over a period of ninety-six hours would probably prove fatal in a majority of cases, it follows that, for this particular explosion, there was sufficient radio-activity in a downwind belt of 270 km × 56 km to have threatened the lives of nearly all persons who remained in the area unprotected for at least ninety-six hours. At greater distances there would have been many cases of sickness resulting in temporary incapacity.

10. Residual radiation, liberated by the decay of nuclear debris, may cause an increase of several hundred times the radiation normally present as background radiation in any area and may seriously inhibit or even prevent local rescue and

FIGURE XIII. ESTIMATED TOTAL-EXPOSURE CONTOURS IN ROENTGENS AT 96 HOURS AFTER THE BRAVO TEST EXPLOSION



relief operations. Apart from the direct hazard of such additional radiation to human beings, there is an indirect hazard from heavy fall-out contamination of soil, plant life and water supplies, through subsequent ingestion of contaminated food supplies. In the incident reported in the previous paragraph, the people exposed at Rongelap, particularly children, also received high doses of radiation to the thyroid due to internal radiation from ingested radio-iodine. Water supplies may well be rendered temporarily unusable. These direct and indirect hazards add to the immediate physical disaster of a nuclear explosion by producing radiation sickness and death for sections of the population who, being on the periphery of the immediate damage area, would otherwise have appeared to survive the explosion. In fact the human casualties may be caused at distances where the immediate physical effects of the explosion are totally absent.

11. It can be calculated that a hypothetical nuclear attack of 10,000 megatons in ground-bursts could, in the course of sixty days, destroy 80 per cent of the population of the United States, if unprotected, while an attack of 20,000 megatons could cover the entire country with radio-active fall-out, killing 95 per cent of the unprotected population. Similarly in the Soviet Union, which has an area greater than that of the United States, a 10,000 megaton blow could wipe out 75 per cent of the population, whereas a 20,000 megaton attack could increase the population losses to around 90 per cent.

12. Fall-out from nuclear explosions still provides a major contribution to the radio-active contamination of our natural environment. The rate at which it is deposited over the world depends on a number of factors, including the total amount of radio-active material remaining in the stratosphere. Any injection of nuclear debris into the stratosphere, as a result of high-yield nuclear explosions, is followed after a period of time by a rise in fall-out rates roughly proportional to the amount injected. In the absence of further atmospheric nuclear tests, depletion of the stratosphere progressively takes place and the rate of fall-out decreases accordingly. The global rates of deposition have been well documented in a series of publications by the United Nations Scientific Committee on the Effects of Atomic Radiation. These relate to studies from the beginning of nuclear tests and continue through the years of public concern about long-term radiation hazards, beginning with the intensive nuclear weapon testing in the atmosphere in the 1950s, and including the intensive atmospheric testing in 1961/1962, immediately before the nuclear test ban treaty of 1963. Although that treaty sought to prohibit any further nuclear weapon testing in the atmosphere, some further testing in the atmosphere has been carried out by two countries which did not sign the test ban treaty. However, the United Nations Scientific Committee reported in 1966 that the atmospheric tests in central Asia up to that year contributed negligibly to the risk of radiation, as compared with that already existing from the previous injection of nuclear debris into the stratosphere.

UNDERWATER EXPLOSIONS

13. In explosion under water, as in the case of a nuclear explosion in the atmosphere, a fire-ball is again formed and the rapid expansion of hot gases initiates a shock wave. But the fire-ball is much smaller, and remains visible only until the bubble of constituent hot high-pressure gases and steam reaches the surface of the water. The shock wave causes a spray dome to rise over the point of burst, with time of rise and height of dome depending on the energy yield of the explosion and the depth of detonation. Details of underwater nuclear explosions carried out in the Pacific in 1946 and 1958 are given in annex III, reference 1.

14. Thermal radiation emitted from the fire-ball while under water would be absorbed by the surrounding water. So, too, is the initial nuclear radiation although, as soon as the fire-ball reaches the surface, gamma radiation from fission

products in the water column and the subsequent radio-active cloud acts as initial nuclear radiation. The water fall-out from the cloud, and the "base surge" (spray rising from water surface), would be responsible for delayed or residual nuclear radiation. Thus, since in this case the "initial" nuclear radiation merges continuously with that produced over a period of time, it is less meaningful to make the same kind of distinction between initial and residual radiation as applies in the case of an explosion in the atmosphere.

15. After an underwater nuclear explosion, most of the radio-activity remaining in the water and on the bottom would be found initially in the vicinity of the explosion. Table 6 shows the rate of spread of radio-active material and the decrease in dose rate, following the shallow underwater explosion in the Pacific in 1946. For detonations in deep water some activity may be left on the surface to diffuse rapidly downward and outward, thus reducing the radio-activity level to safe limits for personnel.

16. Radio-activity falling back from the high airborne cloud on to the sea extends downward much farther than "base surge" contamination or that transported by the water. The fall-out debris quickly mixes with the water and, since the water absorbs (or attenuates) the radiation to a considerable extent, the radio-active hazard is much less than would result from the same fall-out over land. The radio-active material is gradually transported to other locations by prevailing currents and, if these are known, the path of the contaminated water can be predicted.

TABLE 6. DIMENSIONS AND DOSE RATE IN CONTAMINATED WATER AFTER THE 20 KT UNDERWATER EXPLOSION AT BIKINI, 1946

Time after explosion (hours)	*Mean diameter of contaminated area (km)*	*Maximum dose rate (rads per hr)*
4	7.3	3.1
38	7.6	0.42
62	12.0	0.21
86	13.6	0.042
100	15.2	0.025
130	18.4	0.008
200	20.8	0.0004

Annex II

GENETIC EFFECTS OF NUCLEAR RADIATION

1. It has been established by experiment that ionizing radiation can induce changes in hereditary material in plants, in animals and in human beings. Such changes fall into two broad categories: first, gene mutations, consisting of changes in single genes, which are the elementary units of information that form the genetic "message" transmitted by each parent to offspring through the germ cells; secondly, gross chromosome anomalies which are due to loss, duplication or re-arrangement of major or minor parts of the chromosomes in which the genes are contained and thus involve whole blocks of the elementary units that make up the genetic "message". It must be noted that similar genetic changes can also occur spontaneously in human and other species.

2. Geneticists agree that the overwhelming majority of newly occurring genetic changes, whether spontaneous or induced by radiation or any other agent, are detrimental. Individuals carrying the affected genes or chromosomes have a reduced chance of transmitting their genetic "message" because of reduced fertility or reduced likelihood of survival. Eventually these genetic changes will thus be eliminated from the population. Some of them may result in barely noticeable social consequences as when an immature germ cell is lost or a fertilized egg fails to implant. But other changes may cause serious hardship for both an individual and society if they affect the normal developmental patterns in noticeable ways and lead to such damage as mental deficiency or a major physical disability.

3. Since most of the spontaneous mutations in man are believed to be eliminated during the development of either the germ cells or the embryo, they cannot readily be detected; but it has been possible to observe the frequencies of a number of dominant hereditary traits which manifest themselves in the offspring of the individuals who transmit the altered genes, and to estimate the relevant mutation rates. The frequencies of certain spontaneously occurring chromosome anomalies associated with mental and physical defects are also known. Most of these defects are the results of changes which took place in the germ cells of the parents of the affected individuals.

4. No direct information is currently available on the rate of radiation-induction of gene mutations in man. Estimates of the genetic risks arising from ionizing radiation, however, can be based on results of experiments on animals, particularly mice or, in the case of chromosome anomalies, on studies with tissue cultures of human skin and blood exposed to radiation. Experiments on mice confirm results of experiments with lower organisms in showing that the yield of gene mutations is directly proportional to the radiation dose. They also show that the yield per unit dose is lower when the dose is delivered over a long period of time than when delivered instantly. While these experiments have made it possible to describe the mutational effects of irradiation, they do not provide adequate evidence that could be applied to man, regarding the manner or rate with which induced gene mutations would be eliminated from the population, or the proportion of mutations that would have serious consequences. It is not, therefore, possible to assess how many, say, crippled or mentally defective individuals would appear in any generation descended from irradiated individuals, and the total number summed over all generations is also highly uncertain. The limitations of the experiments, and the assumptions made, lead to widely ranging quantitative

estimates of the frequency of possible defects in offspring. Except for the purpose of ruling out some of the most extreme possibilities, these estimates are of limited value and are, therefore, not included here.

5. Unlike gene mutations, radiation-induced chromosome anomalies have been directly observed in body tissues of irradiated human beings. They have also been studied in a wide number of plant and animal species, including mice and monkeys where they have been directly observed in immature germ cells. Again, as for gene mutations, the yield of chromosome anomalies depends on the radiation dose but the relationship between dose and frequency of anomalies is more complicated than for gene mutations and, where low doses are involved, is less well known. On the basis of somewhat arbitrary assumptions, it is possible to obtain quantitative estimates of the rate of induction by radiation of a few types of chromosome anomalies known to be associated with certain severe physical and mental defects in man, but how much weight could be attached to such estimates is uncertain. More important, nothing is known about the likely rates of induction of other, more common, chromosome anomalies which, in non-irradiated populations, are present in, and seriously affect, about 1 per cent of all live-born children, and are also responsible for about 4 per cent of all spontaneous miscarriages.

6. Most of the known defects associated with chromosome anomalies are so severe as to preclude reproduction of the individuals who are affected. A large fraction of the induced chromosome anomalies can, therefore, be expected to involve at most the immediate, first-generation offspring of the individuals in which they have arisen.

7. In general, the long-term genetic effects of nuclear radiation in living organisms are cumulative. While no visible injury would accompany the induction of genetic changes in the exposed individuals, undesirable consequences would arise in succeeding generations until the changes were eliminated from the population by their own detriment. Study of the effect of massive radiation, on a specific population, requires a thorough analysis of the relationship between the doses delivered and the frequencies of the changes produced. It also demands a global evaluation of the social as well as the biological consequences of these effects. Lack of information on radio-genetics, together with uncertainty about the amount of radiation to which a population would be exposed in any given nuclear war, makes calculations about genetic damage very unreliable. But it is reasonably certain that a population which had been irradiated at an intensity sufficient to kill even a few per cent of its members, would suffer important long-term consequences.

Annex III

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Annex IV

BASIC COSTS OF NUCLEAR WARHEADS

FISSIONABLE MATERIALS

1. The three materials suitable for the application as a nuclear explosive are uranium-235, plutonium-239 and uranium-233. They all possess the main properties required, i.e., long half-life, a sufficient high probability for fission and low probability for spontaneous fission. Uranium-233 is not known to have been used in nuclear explosives, and the cost of this material has therefore not been considered here.

URANIUM-235

2. Natural uranium contains 0.7 per cent of uranium-235 while the main component is uranium-238. For use as a nuclear explosive the uranium-235 is usually enriched to 90-95 per cent. Several processes, i.e., gaseous diffusion, thermal diffusion and electromagnetic separation, have been developed for this purpose. Of these, only the gaseous diffusion process is known to be applied at present. Thermal diffusion and electromagnetic separation were used for developing the first United States nuclear weapons, but both processes were abandoned after the Second World War because of high costs. The total United States investments in these two methods have been around $US 460 million (1).*

3. The gas centrifuge, which may prove to be a useful separation tool, is still at the developmental stage.

4. The gaseous diffusion process is used today in France, the United Kingdom, the United States and is believed to be used also in the USSR and China. This method involves some 4,000 enrichment stages and large and costly plants based on advanced technology are required. The exact technology is largely classified. The USAEC operates today three such plants. The cost of the first plant was around $1,000 million, and of the two subsequent plants a total of $1,300 million, and it has been assumed that the cost of one such plant of economic size is in the range of $750 million to $1,000 million (2).

5. The capacity of these three plants has recently been published by the USAEC.[a] In terms of separative capacity for producing highly enriched uranium-235 the total was about 17 million kilogrammes per year of natural uranium feed for the quoted 0.2531 per cent uranium-235 content of the depleted residue. If the yearly operating costs amount to $500-600 million the corresponding cost in terms of separative work units (i.e., per kg of natural uranium feed for light enrichment and the quoted depletion) is about $30 to $35 per kg unit.

6. The uranium-235 product is 4.5 grammes per kg of natural uranium and the separative work cost is $6,700 to $7,800 per kg uranium-235, or a total cost of $11,000 to $12,000 per kg U-235 from natural uranium at $20 per kg. These cost estimates are in agreement with a statement made by the Forum Study Committee on Toll Enrichment (3) that the separative costs in new United States

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* Figures in parentheses are references to documents in the list appended to this annex.

[a] USAEC press release, 14 June 1967.

diffusion plants need not exceed $30 per kg of separative work in the years to come, whether these plants are owned privately or by the USAEC.

7. Some twenty-five kilogrammes of weapons-grade uranium would be required for the production of one nuclear warhead with a yield in the twenty-kiloton range (4). Uranium-235 is preferred over plutonium for the production of thermonuclear weapons.

8. The gas centrifuge would on the other hand be suitable for producing small quantities of uranium-235. However, the current technology has been classified by most countries conducting centrifuge research, and up-to-date information regarding the status of the technology and costs beyond those related to the original Zippe machine (5) are therefore sparse. A plant capable of producing fifty kilogrammes of 90-per-cent enriched uranium-235 per year would, according to this information (5), cost around $130 million and have annual operating costs of about $13 million. With 10 per cent annual investment charge the production costs would amount to $500,000 per kg uranium-235.

PLUTONIUM-239

9. Plutonium-239 is produced in a nuclear reactor when the uranium-238 contained in the fuel elements is subjected to neutron flux. Other, non-fissile plutonium isotopes, particularly plutonium-240, are produced simultaneously, and the relative fraction of such isotopes increases with the irradiation time. In weapons-grade plutonium the non-fissile fraction should be 10 per cent or preferably less, and this necessitates fuel burn-ups below about 1,000 MWd/tU. For comparison it should be mentioned that the fuel burn-up in natural uranium power reactors is an order of magnitude higher.

10. It is estimated that some eight kilogrammes of 95 per cent plutonium-239 would be required for the construction of one nuclear warhead with a yield around 20 kilotons (4).

11. A complete plutonium-239 production complex would require a uranium refinery (and eventually a metals ingot plant), a fuel fabrication plant, a reactor, a plutonium extraction plant, a plutonium metals reduction plant and related service facilities.

12. The costs of a complex designed for integrated production of some eight kilogrammes (95 per cent) plutonium-239 per year and concentrated around a 40-50 MWth heavy water cooled and moderated reactor with a throughput of 20 tons metallic natural fuel per year can be estimated as follows (table 1):

TABLE 1. PRODUCTION COSTS FOR ≈ 8 KG WEAPONS-GRADE PLUTONIUM PER YEAR
(In $US millions)

	Capital costs	*Annual operating costs*	*Ref.*
Refinery and metals ingot plant	2.50	1.75	(6)
Fuel and fuel fabrication	1.50	0.60	(7)
Reactor	10.00	1.20	
Plutonium extraction	1.25	0.17	(8)
Plutonium fabrication	0.25	0.18	(8)
Service facilities	6.50	0.87	(8)
GRAND TOTAL	22.00	≈ 4.80	

The reactor capital and operating costs are based on information concerning the Canadian reactor NRX (9).

13. Because of the small quantities involved, the plutonium recovery costs have been based on a batch ion exchange process and not on the conventional, continuous solvent extraction process employed for large-scale operation.

14. A Swedish study made for the purpose of this report concerning the cost of producing 40/80/160 kg of weapons-grade plutonium-239 per year has been carried out (4). Plutonium production reactors in the power range 250-500 MWth and a 350 MWth power reactor have been considered, assuming that the reactors were to be moderated with heavy water and fuelled with natural uranium. The plutonium production reactor fuel elements are made up of metallic uranium rods clad in aluminium and the power production reactor is fuelled with uranium dioxide pellets clad in Zircaloy-2. The study does not include investments in facilities for uranium ore milling and concentration and is therefore based on a price of $8 per pound of the concentrate (U_3O_8) bought on the open market. It has been assumed that refuelling of the reactors can be carried out on-load. Table 2 below covers the power reactor alternative, and table 3 the plutonium production reactor alternative.

TABLE 2. PRODUCTION COSTS FOR 40 AND 80 KG OF WEAPONS-GRADE PLUTONIUM PER YEAR IN A 350 MWTH POWER REACTOR
(In $US millions)

Plutonium production:	*40 kg/year*		*80 kg/year*	
	Capital costs	*Annual costs*	*Capital costs*	*Annual costs*
Fuel, conversion and fuel element plant	5.0	8.0	6.0	15.0
Reactor (additional costs, not needed for power)	1.0	1.0	1.0	2.0
Reprocessing and plutonium conversion	28.0	3.0	32.0	4.0
GRAND TOTAL	34.0	12.0	39.0	21.0

TABLE 3. PRODUCTION COSTS FOR 80 AND 160 KG OF WEAPONS-GRADE PLUTONIUM PER YEAR IN PRODUCTION REACTORS
(In $US millions)

Reactor size:	*250 MWth*		*500 MWth*	
Plutonium production:	*80 kg/year*		*160 kg/year*	
	Capital costs	*Annual costs*	*Capital costs*	*Annual costs*
Fuel, conversion and fuel element plant	4.0	2.5	5.0	3.7
Reactor	33.0	1.4	38.0	1.8
Reprocessing and plutonium conversion	36.0	3.5	40.0	4.0
Miscellaneous	4.0		4.0	
GRAND TOTAL	77.0	7.4	87.0	9.5

15. The costs of producing weapons-grade plutonium in a small fraction of the core of a 600 MWe power reactor of the CANDU-type using standard fuel

elements have also been considered, on the assumption that the cost of electricity production should be independent of the plutonium production, i.e., as if the complete core comprised fuel elements yielding maximum burn-up. This means that the reactor operating costs related to plutonium production would be proportional to the costs of plutonium-producing fuel elements at least in the low quantity range, say 8-40 kg of weapons-grade plutonium per year. It has also been assumed that a throughput of fuel corresponding to two tons of U per year with a burn-up around 600 MWd/tU would be required to produce one kg of weapons-grade plutonium. The calculations have further been based on 6,000 hrs reactor operation per year and costs of fuel and fuel element production of $72.50 per kg U contained. The resulting cost of plutonium before reprocessing would be $133,000 per kg. Taking reprocessing costs in the Swedish study (4), i.e., $70 per kg U, the costs of $270,000 per kg weapons-grade plutonium would result.

16. Table 4 summarizes our results concerning plutonium production. In figure XIV the costs per kg are shown as a function of the production capacity.

TABLE 4. METALLIC WEAPONS-GRADE PLUTONIUM PRODUCTION COSTS
(In $US millions)

Production capacity, kg Pu/year	*Reactor type and MWth*	*Capital costs*	*Operating costs (per year)*	*Plutonium costs (10 per cent annual investment charge) (per kg)*
8	Production (50)	22.00	4.80	0.90
10-50	Power (600 MWe)			0.27
40	Power (350)	34.00	12.00	0.39
80	Power (350)	39.00	21.00	0.31
80	Production (250)	77.00	7.40	0.19
160	Production (500)	87.00	9.50	0.12

17. From the data arrived at for the costs of gaseous diffusion, and production of plutonium-239, and in view of the lack of reliable data concerning gas centrifuge costs, it would seem that a country desiring to build one or a minor number of nuclear warheads per year would go for the plutonium type.

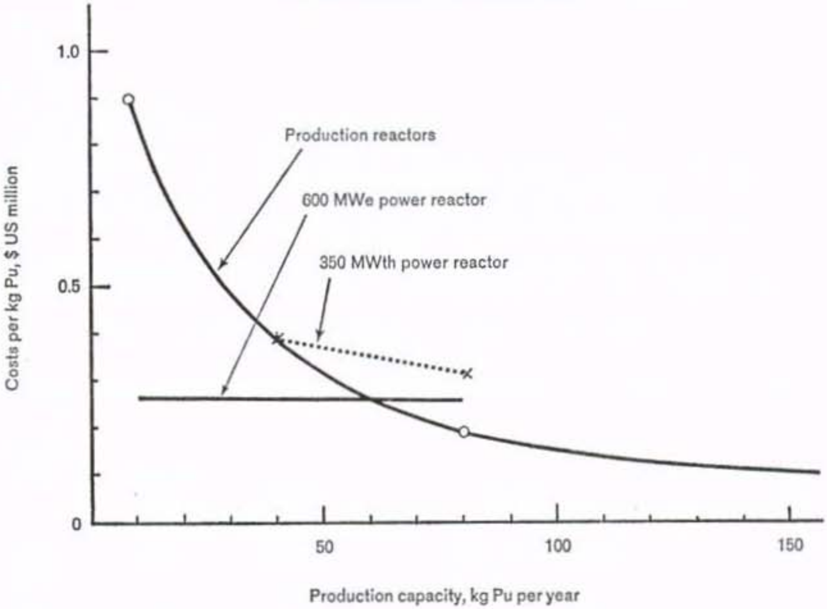
18. A small programme, aiming at the production over a ten-year period of ten warheads, each with a yield of about twenty kilotons, would require a total of 80 kg plutonium. The corresponding total plutonium procurement costs based on a 50 kWth production reactor would comprise some $22 million in capital costs and around $48 million for operation, altogether, i.e., $7 million per year, or approximately $0.9 million per kg of plutonium.

19. If an equivalent quantity of plutonium was to be produced in conjunction with electricity production in a large (600 MWe) power reactor, the corresponding total costs would amount to some $22 million, i.e., $2.2 million per year, or around $0.27 million per kg of plutonium.

20. A moderate programme, aiming at the production over a ten-year period of 100 nuclear warheads of the same size as above, would, based on a 250 MWth production reactor with an output of 80 kg plutonium per year, involve total costs of $151 million, of which $77 million would be capital costs and $74 million operating costs. The corresponding annual costs would be $15 million and the plutonium costs $0.19 million per kg. Doubling the production capacity to 160 kg per year aiming at the procurement of 200 warheads over a ten-year period would result in capital and operating costs of $87 million and $95 million respectively. The annual costs would be $19 million and the plutonium production costs $0.12 million per kg.

FIGURE XIV. COSTS OF WEAPONS-GRADE PLUTONIUM *vs* ANNUAL PRODUCTION CAPACITY

(10 per cent annual investment charge)



21. From figure XIV it can be seen that plutonium production based on a large power reactor would be far more expensive when the production rate is increased.

DESIGNING AND MANUFACTURING

22. The amount of published information on problems related to warhead assembly is severely limited by military secrecy. Some very general evaluations of the nature of the problem can, however, be made. Bomb construction includes such activities as detailed measurements of bomb material properties, weapons design, final metallurgical treatment of explosives, manufacture of fusing and detonation equipment, etc. The fabrication of plutonium bombs is complicated by several factors, such as complex metallurgy, toxicity and chemical reactivity of the metallic charge. In addition, the design and construction of shaped charges for explosion detonation presumably represent challenging problems. However, various countries possess this technology since shaped charges are used in such weapons as the bazooka and for perforators, oil-well casings and open hearth furnace tappers.

23. According to one source (10) the cost of assembling from two to three bombs per year would comprise some $10 million in capital investments and annual operating costs of some $5 million. According to the more recent Swedish study (4) the capital investments in a factory for assembling ten warheads per year would be about $8 million and the annual operating costs around $1 million. The Swedish figures have been used in assessing the total costs given in the section on various warhead production programmes below.

24. Without knowing the complete requirements that a country considering a first nuclear test might levy on the test programme, the cost of tests can only be assessed in a most general manner.

25. The factors a country conducting a first nuclear test might consider are:

(*a*) The environment of the test, i.e., above the earth's surface, on the surface, underground or under water;

(*b*) The diagnostics of the explosion;

(*c*) The weapons-effects tests to be made.

26. Tests at or near the earth's surface (balloon- or tower-suspended, free-fall or rocket-launched) would provide the greatest amount of data for the lowest cost. The absolute costs would, however, depend largely on the complexity of the experiments performed, the cost of accommodations and the number of people involved, and would therefore be difficult to state.

27. A nation signatory to the limited test-ban treaty would be constrained to testing underground, either in a hole drilled for the purpose, or in a mine. A few examples of costs involved in connexion with such tests will be given below.

28. A test with a 20-kiloton bomb would require a drilled hole 1,100 feet deep and 90 inches in diameter. United States costs for such a hole in dry tuff would be some $0.35 million. Drilling under other conditions could easily double the costs. Costs for sealing to prevent venting would have to be added. Few countries, however, are known to have digging equipment for deep holes with this diameter. The simplest diagnostic test a country could conduct for an underground test would be to get a crude determination of yield. A determination good to about ±40 per cent can be obtained by using surface seismometers in the vicinity of zero-ground, and would cost a few thousand dollars. A determination to about ±20 per cent can be obtained by digging a series of holes extending radially outward from the device hole for the installation of accelerometers and seismometers. The determination would in this case cost hundreds of thousands of dollars.

29. The best yield determination could be obtained by drilling back to the vicinity of the explosion and performing radio-chemical analyses of device debris. This procedure could easily be as expensive as drilling the original hole.

30. The Long Shot event, conducted at Amchitka Island in 1965 for seismological calibration of the Aleutian chain area, is a good example of the basic costs (exclusive of the explosion device) for such tests carried out in a remote area. The costs are broken down in table 5.

TABLE 5. COST OF THE LONG SHOT EVENT
(*In $US millions*)

Exploratory work to determine the feasibility of using the area...	2.61
Establishing the base	4.50
Drilling and sealing	1.87
Emplacing equipment in the hole	0.16
All other expenditures	1.52
GRAND TOTAL	10.66

31. For comparison, it could be mentioned that the USAEC Nevada test site represents an investment of $150 million, and that AEC for the period 1 July 1965 to 30 June 1966 spent about $200 million for underground testing, exclusive of the cost of the fissionable material used.

32. It would presumably be cheaper to conduct the test in an established mine since little new digging and construction would be required for sub-shafts and zero room. The gauges for device diagnostics would be installed in the zero room enclosure. Device yield measurements can be made by gauges installed in the drift mined for device emplacement. The yield would be determined by hydrodynamic measurements. A minimal amount of diagnostic or device design and operation information can be obtained by recording the rate of release of energy from the device, i.e., the "Alpha". The costs of a test conducted in a mine have been estimated as shown in table 6.

TABLE 6. COST OF AN UNDERGROUND WEAPONS TEST PERFORMED IN A MINE
(In US dollars)

Access	70,000
Headframe excavation and installation	130,000
Shaft and drift complex	1,156,000
Zero room	60,000
Instrumentation installation and operation	55,000
Timing and firing installation and operation	50,000
Device installation	10,000
Stemming	400,000
Technical direction	90,000
Administration	160,000
GRAND TOTAL	2,182,000

33. These costs are exclusive of the device itself, the instrumentation recording equipment and the timing and firing system, and are based on costs for similar type construction at the United States Nevada Test Site.

34. According to Swedish estimates (4), the total costs of testing one 20-kiloton device underground would amount to $12 million, and the costs of testing four such devices would amount to $15 million.

35. According to the costs of the Long Shot event (table 5) and the above cost estimate for a test performed in a mine, the Swedish cost estimate may well be a realistic one.

COSTS FOR VARIOUS WARHEAD PRODUCTION PROGRAMMES

Plutonium warhead production programme

36. Based on the estimated cost figures for plutonium production and warhead design, manufacture and testing given above, the total costs of a small programme (one 20-kiloton warhead per year over ten years) and a moderate programme (ten 20-kiloton warheads per year over ten years) are shown in table 7. The small programme would cost $11 million per year, i.e., $11 million per warhead, whereas the moderate programme would cost $20 million per year, resulting in a warhead unit price of $2 million. If the small programme could be combined with plutonium production in a large power reactor, the annual costs might be reduced to $6 million, and consequently the warhead unit costs to $6 million.

Production programme including thermonuclear warheads

37. The escalation of the total warheads production costs resulting from the construction and operation of a diffusion plant for enriching uranium-235 and the development and testing of thermonuclear weapons is well demonstrated in the French example shown in table 8. The gaseous diffusion plant was built after 1960.

TABLE 7. ESTIMATED COSTS FOR VARIOUS PLUTONIUM-BASED WARHEAD PRODUCTION PROGRAMMES
(In $US millions)

	Small programme (estimate)[a] *(10 × 20 kiloton devices over 10 years)*					*Moderate programme (estimate)*[a] *(100 × 20 kiloton devices over 10 years)*		
	Capital costs			*Annual operating costs × 10*		*Capital costs*		*Annual operating costs × 10*
Plutonium metal	22.0	(0)[b]		48.0	(22.0)[b]	77.0		74.0
Design and manufacture	8.0	(8.0)[b]		10.0	(10.0)[b]	8.0		10.0
Testing				12.0[c]	(12.0)[b]			15.0[d]
Storage, maintenance				4.0[e]	(4.0)[b]			4.0[e]
TOTAL	30.0	(8.0)		74.0	(48.0)[b]	85.0		103.0
GRAND TOTAL		104.0	(56.0)[b]				188.0	
Annual average		11.0	(6.0)[b]				19.0	
Cost per warhead		11.0	(6.0)[b]				1.9	

[a] Figures from table 1.
[b] Figures from table 1, large (600 MWe) power reactor.
[c] One test (Swedish estimate).
[d] Four tests (Swedish estimate).
[e] Figures from ref. (4).

TABLE 8. COSTS OF TOTAL FRENCH NUCLEAR WARHEADS PROGRAMME[a]
(*In $US millions*)

	Fissile material	*Design and manufacture*	*Testing*	*Total*
To 1960	160	40	40	240
1960-1964	880	460	300	1,640
1965-1970		Details not specified		3,180
GRAND TOTAL	1,040 (to 1964)	500 (to 1964)	340 (to 1964)	5,060

[a] It is expected that costs will stabilize after 1970. The figures are taken from ref. (11).

COSTS OF DELIVERY VEHICLES

General considerations

38. The basic premise taken herein is that nuclear forces are created to achieve military and political objectives which require the force to be credible and effective. Thus the costs of approaches employing weapons assembled and hidden on enemy territory, delivered by ship or by commercial aircraft or other unorthodox means of delivery are ruled out. Consideration is therefore limited to nuclear-capable military bomber aircraft or ballistic missile forces which can play a "strategic" role. In addition to the delivery vehicles *per se,* there must be created the necessary bases; launching sites; supporting systems (maintenance, logistics, defence etc.); and command, control and communications system, to establish a force of military and political value which is safe from unauthorized or accidental employment.

39. Range requirements, together with the physical characteristics of the nuclear weapon, will affect the size of the delivery vehicle (i.e., relatively small and sophisticated weapons for small vehicles). The characteristics of the adversary's targets and the nature of the defences employed to protect them will play an important part in determining the type of force and the required accuracy of weapon delivery. Early warning systems would have to be provided for these nuclear forces, backed up by anti-aircraft defences, interceptors, dispersed airfields etc., for a bomber fleet, and hardening or mobility for missiles.

40. In formulating the costs for a proposed programme the cost of acquisition of the delivery systems, the costs of all of the related support systems discussed above, and the costs of operation and maintenance ought to be included. In the case of bombers, supporting equipment and facilities, including airfields, refuelling planes, large maintenance and overhaul depots, etc., are needed. In the case of missiles, launch, overhaul and maintenance facilities are required. Missile launching submarines require their own supporting facilities, including shipyards and/or tenders. It is possible to have the relatively low acquisition costs obtained through purchasing old aircraft offset by higher operating costs. Missile system operating costs, which are lower than aircraft, are offset by the generally higher acquisition cost.

41. From another standpoint, there are also the costs needed to maintain the effectiveness of the force in light of its obsolescence, caused in part by countermeasures triggered by its deployment. The latter costs can consist of extensive modernization costs of the deployment vehicles, such as adapting aircraft to cope with an adversary's air defence, or the replacement of the force by succeeding generations of delivery vehicles.

42. The accuracy with which delivery vehicle costs are predicted has been

notoriously poor. Heavy overruns of expenditures have been the rule rather than the exception, and have been concurrent with lengthy delays in the projected time-tables. Many instances exist of the deployment of extremely costly but already obsolescent weapons systems, which were withdrawn a very short time after their initial deployment. Furthermore, while it is not always correct, it can be generally assumed that the accuracy of cost and time estimates for both the development and production of delivery vehicles is a function of prior related experience. Overruns are therefore more likely to be incurred when a country embarks on its first generation development.

43. The time needed to develop a delivery system depends on the existing industrial base and related experience, and would, in most cases, take at least ten years for reasonably industrialized nations. Costs can be spread over time, but peaks occur at certain points. Obsolescence and countermeasures costs are related to the time factor.

44. Monetary costs do not, by themselves, give a realistic picture of the necessary effort in terms of over-all resources. A sizable technological base is needed to create and maintain a force of delivery vehicles. Included here are the necessary skilled workers, engineers, scientists and managers, fabricating facilities, experimental facilities, test ranges, etc. Even if major components can be purchased abroad, the delivery system must be integrated into a workable whole, and this process requires the skills of a large number of qualified persons.

45. Licensed production abroad tends to increase costs because of language and measurement standards, translation, travel time, labour unfamiliarity with advanced technological processes, royalty payments, small production runs and lack of established industry with its tools and labour skills.

46. It should be noted that the French and United Kingdom programmes are aimed at the establishment of a credible modern force; while they are small compared to the United States effort, they are nevertheless judged by responsible officials in those countries as providing the lower limit of a suitable strategic nuclear force. The United States expenditures in this field represent an effort in order of magnitude costlier than the combined United Kingdom-French programmes. This is due to both the preponderantly larger United States force involved and the much longer time period this force has been in existence. The over-all delivery vehicle expenditures for these three nations are estimated as: France (1960-1970)—$2,780 million; United Kingdom (1956-1967)—$4,107 million; and United States (1948-1970)—$110,500 million. Undoubtedly, less expensive programmes can be envisaged for other countries in other circumstances. However, in general, even a modest indigenous delivery vehicle programme including nuclear weapons would entail expenditures of no less than $1,500 million.

47. Many nations already have a present or easily realizable delivery vehicle capability of some sort, such as aging bombers, short-range fighter-bombers and large space rockets. However, given plausible interest in deploying credible forces coupled with the strategic requirements at hand, few of these nations actually have an acceptable nuclear delivery vehicle (12).

COSTS OF ELEMENTARY DELIVERY SYSTEMS

Aircraft

48. The lowest level of expenditure for such a system could be achieved through, say, purchasing a force of thirty to fifty Canberra, B-57, or similar bombers. This type of aircraft can carry nuclear weapons, although unrefuelled range is limited.

49. The acquisition and operating costs of such a system have been estimated as follows (in millions of US dollars) (13):

	Acquisition costs	*Annual operating costs*
Aircraft, spares, tankers and related equipment......	120	15
Protection; dispersed basing, simple penetration aids, fighters and anti-aircraft	60	10
TOTAL	180	25

50. As an example of production costs, a B-29 propeller-driven bomber produced in the United States costs $1.2 million plus an almost equivalent value of government material (14).

Missiles

51. An elementary surface-to-surface missile force can be considered to consist of approximately fifty short-range or intermediate-range missiles in soft emplacements. Such an elementary force is likely to have low reliability and could probably only launch a small fraction of its missiles in a co-ordinated attack. Since it is unlikely that a missile force can be purchased at present, indigenous development would be required even if certain major components such as the boosters might be purchased. Guidance and control of the booster is required in order to make the missile a credible strategic threat; the development of these systems is considered the most critical and expensive (15). A typical industrialized nation might spend from eight to ten years on such a programme (15).

52. The acquisition and operating costs of such systems with missile ranges of 500 and 1,500 n.mi., respectively, have been estimated as follows (in millions of US dollars):

	Acquisition costs		*Annual operating costs*	
	500 n.mi range	*1,500 n.mi. range*	*500 n.mi range*	*1,500 n.mi. range*
Missiles, including development, procurement and soft sites deployment (16)	400-500	745-860	5	10
Protection	40	40		
TOTAL	440-540	785-900	5	10

53. The United States Thor is an example of an early strategic missile programme. This 1,500 n.mi.-range missile was deployed at soft sites in the United Kingdom for several years. The cost of development was somewhat lower than normal, since the Thor shared several of its systems with the Atlas missile in that the propulsion systems were very similar, and the Thor re-entry vehicles were identical with the early Atlas re-entry vehicles. The total costs of the programme have been estimated at $600 million (16).

54. The British Blue Streak programme was comparable to the Thor in that it was a soft-based liquid propellant missile. The Blue Streak had a design range of 2,500 n.mi. Due to time-table slippages, cost overruns and the recognized obsolescence and vulnerability of soft basing and slow reaction time, the Blue Streak was cancelled during its development, after approximate expenditures of $300 million (17, 18). It was estimated that an additional $1,700 million would have been expended to complete its development and to deploy a force from soft sites in over eleven years (18, 19). British missile costs have on several occasions escalated and resulted in programme cancellations (20, 21, 22).

55. The total acquisition cost for a force of thirteen Atlas squadrons with

some 140 missiles with launch facilities is estimated at $4,900 million (23). This is about $35 million per missile. Resources required in terms of capital investment for production and construction alone is about $153 million per squadron after development is completed (24). The cost of an Atlas missile vehicle without warheads is $1.9 million (23). A soft Atlas launch facility costs over $27 million, and establishment of the facility involved a massive complex industrial effort lasting some two years (25). Each Atlas costs $1 million per year to maintain, with eighty trained men to support every missile (26).

COSTS OF MEDIUM-LEVEL DELIVERY SYSTEMS

Aircraft

56. A medium-level aircraft delivery system can be considered to consist of a force of high performance aircraft, with their related tankers, bases, maintenance facilities, command and control system, etc. The French Mirage IVA bomber system is an example of such a force. The aircraft was an outgrowth of a Mirage fighter of the mid-1950s, took more than six years to develop and deploy, and will be phased out by ballistic missiles in the 1970s. The total acquisition costs are expected to be around $940 million, and the annual operating costs around $100 million (11). The total costs of the Mirage force including operation over ten years could therefore be close to $2,000 million.

57. The British V-bomber force, comprising three models of subsonic medium bombers is another example of medium-level aircraft delivery systems. Approximately 300 bombers were built of which probably less than 200 were operational at any one time. A proportion of the force is equipped with the Blue Steel air-to-surface missile. The total acquisition costs have been estimated at $1,800 million, inclusive of the Blue Steel, and the annual operation costs at $120 million. The British, in general, have had severe problems in developing and maintaining the capabilities for producing advanced aircraft (27).

58. One estimate put the price of an early-production B-47 at $3.4 million plus an almost comparable value of government-furnished equipment (28). The cost of one hour's flying is $500 (29). An examination of the United States B-47 programme reveals some idea of the resources required to undertake such a programme. Employment at Boeing's Wichita, Kansas, plant was above 22,000, several thousand in excess of the force which turned out a record 100 B-29s a month in the closing phase of the Second World War. When the go-ahead was given on the B-47, employment was only 1,500 workers (30). A 3-million-square-foot plant, closed at war's end, was reopened and housed $29 million worth of machinery. In addition, large wartime plants were reactivated by Douglas and Lockheed for the production of B-47s with Boeing-furnished engineering and tooling (31). The initial B-47 tooling at Seattle alone cost $52.5 million with a similar cost at Wichita.

Missiles

59. The Minuteman I, which is deployed in hard underground launch sites can be considered an example of a medium-level 5,000 n.mi.-range missile system. While actual Minuteman I procurement totalled over 800 missiles, the procurement costs for the "first batch" of approximately fifty can be estimated at $2 million each (32). It should be noted that the cost of basing a Minuteman is approximately $3 million, exclusive of the cost of the missile (33). For a force of fifty Minuteman I missiles, the missile procurement costs including development would be $1,100 million; the costs of basing in hard emplacement about $150 million. Adding annual operating costs of $5 million (34), brings the total costs to $1,300 million over a ten-year period, or $130 million per year.

60. The French SSBS missile system is similar to Minuteman I in many respects, the major difference being that the SSBS has a 2,000 n.mi. maximum

range. It is expected that approximately twenty-five missiles will be deployed in hardened underground emplacements. Since the SSBS programme is far from completed, the programmed acquisition costs are liable to overrun, and operating costs must be considered. An estimate of the procurement costs is $700 million (35). The SSBS programme will cover a period of almost ten years to operational deployment, and was built upon a basic research rocket capability (36). Industrial and resource requirement, especially test facilities, are extensive (37).

61. The total acquisition cost for a force of fourteen Titan squadrons comprising 140 Titan I and Titan II missiles is estimated at $4,900 million. Resources required for construction of fourteen squadrons is $796 million (38). As a general rule, for strategic ballistic missiles, 80 per cent of the total cost is taken by ground-based facilities (39). The industrial and resource effort required to build one hardened launch complex with nine missiles in underground silos involves the use of large-scale earth-moving equipment, specialized fuel-handling equipment, etc., and is roughly comparable to putting a ten-storey building underground (25). The Titan missile production facility at Denver costs about $52 million (40).

COSTS OF A SOPHISTICATED DELIVERY SYSTEM

Aircraft

62. The only sophisticated bomber aircraft delivery system presently under development is the FB-111, in the United States. The estimated costs for the acquisition of a force of 210 aircraft equipped with SRAM air-to-surface missiles are given as $2,173 million (41). It should be noted that these estimates are subject to further overruns, and that the FB-111 is a derivative of the F-111, thus a major portion of its development cost was charged off as part of the fighter development programme (42). The operating costs of this force up to 1971 will be $342 million (41).

63. The United Kingdom cancelled an advanced supersonic bomber (TSR.2) because of escalating and intolerable costs. It is estimated that 150 aircraft would have cost $2,000 million, at a unit rate of $14 million (43).

64. A model has been derived for computing monetary, manpower and facility requirements for supersonic combat aircraft of up to 100,000 pounds gross weight (44). Cost data, calculated from these models, for a hypothetical aircraft of 65,000 pounds maximum take-off weight would be as follows:

Design and development	$520 million
Engineer man-hours through prototype	12 million man-hours
Factory employment with a production rate of 12 units per month	13,200
Factory floor-space requirement with a production rate of 12 units per month	3,120,000 sq. ft.

Missiles

65. An example of a small-size sophisticated missile delivery system is the French MSBS system to consist of three missile-launching nuclear submarines, each armed with sixteen missiles of 1,500 n.mi. range. Three submarines are needed to assure that two of them are on station at all times. The procurement costs for this strategic nuclear force has been estimated at $1,000 million (35), and the estimate for the annual operating costs is $20 million. According to reference (11) the total French costs for missile-launching nuclear submarines and the MSBS and SSBS system will through 1970 be $1,840 million, which is slightly higher than the total of the SSBS costs given in chapter 2.3.1.2 ($700 million) and the above procurement costs ($1,000 million). It should be noted that the estimated costs given below are subject to possible overruns. In addition, the

MSBS and the SSBS share many components, so that the development costs are not always easy to distinguish.

66. An example of a large force of sophisticated delivery vehicles is the United States Navy's Polaris programme. The ultimate deployment of this force will total forty-one submarines carrying sixteen missiles each. The missiles have been developed and procured in three versions: A-1, A-2 and A-3. The first of these has already been phased out. The Polaris A-2 will be replaced by the new Poseidon missile in the future, necessitating modifications to the submarines, as well as the development and procurement of the missiles. The estimated costs of the Polaris programmes, including the missiles, submarines and supporting facilities, are expected to exceed $13,000 million by 1970 (45).

SUMMARY OF DELIVERY VEHICLE COST DATA

67. A summary of procurement and operation costs for the various categories of delivery vehicle systems is given in table 9.

AN EXAMPLE OF ESCALATING COSTS AND COUNTERMEASURES

United States delivery vehicle costs[b]

68. The list of aircraft deployed and programmed in this category includes the following: B-36, B-47, B-50, B-52, B-58, FB-111, KC-97 and KC-135. These aircraft exceed 4,500 in number. Added to these are the Rascal, Hound Dog, Quail and SRAM, all missiles with procurements in the hundreds. In addition, there were several aircraft developed either as prototypes, such as the XB-60 and XB-70, or produced in limited quantities, such as the B-45. Several air-to-surface missiles (Skybolt and Goose) were cancelled in development. An estimate of the R and D procurement, and base construction costs associated with the above, is on the order of $28,000 million. The estimated operating costs associated with the deployed aircraft systems are on the order of $31,500 million. These operating costs do not include the anticipated operating costs of the FB-111 force, nor the cost of the logistic and defensive forces required for the support and protection of the offensive forces. The strategic missile costs include the R and D and acquisition of missiles and the construction costs of the missile sites (soft and hard) and the missile submarines and their supporting ships. Included among the ballistic missile systems are: Thor, Jupiter, Atlas, Titan, Minuteman, Polaris and Poseidon. In addition, there were several cruise missiles developed (some of these were deployed for varying lengths of time), including Mace, Regulus, Snark and Navaho. The estimated investment costs associated with these systems are $37,000 million.

69. The operating costs associated with the missiles and their test activities are estimated to be $14,000 million.

70. The United States delivery vehicle costs can be summarized as follows:

	$US millions
Strategic aircraft systems:	
Acquisition cost	28,000
Operating cost, 1950-1970	31,500
SUBTOTAL	59,500
Strategic missile systems:	
Acquisition cost	37,000
Operating cost, 1960-1970	14,000
SUBTOTAL	51,000

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[b] United States Department of Defense 1967 Appropriation Hearings.

TABLE 9. SUMMARY OF DELIVERY VEHICLE PROCUREMENT AND OPERATIONS COSTS
(In $US millions)

System category	*System description*	*Procurement costs*	*Annual operating costs*
Aircraft, elementary	30-50 bombers (Canberra, B-57)	180	25
Missile, elementary	50 missiles in soft emplacement, 500 n.mi. range	440-540	5
	50 missiles in soft emplacement, 1,500 n.mi. range	800-900	10
	US Thor missile	600	Not available
	13 US Atlas squadrons (~140 missiles)	4,900	2 per missile
Aircraft, medium-level	50-60 French Mirage IV bombers	940	100
	300 British V-bombers (3 types) with air-to-surface missiles	1,800	120
Missile, medium-level	50 Minuteman I, in hard emplacement, 5,000 n.mi. range	1,250	5
	25 French SSBS in hard emplacement, 2,000 n.mi. range	700	Not available
	14 US Titan squadrons (~140 missiles)	4,900	Not available
Aircraft, sophisticated	210 US FB-111 with SRAM air-to-surface missiles	2,200	340 (total to 1971)
Missile, sophisticated	3 French missile-launching nuclear submarines, each with 16 missiles of 1,500 n.mi. range	1,000	20
	41 US Polaris-launching submarines, each with 16 missiles	13,000	Not available

71. Through the fiscal year 1965 the United States had invested nearly $45,000 million for the research and development, procurement, and related military construction associated with the weapons currently in the strategic retaliatory forces, including:

$US millions	
10,100	for 14 wings (630 UE aircraft) of B-52 heavy bombers
3,100	for 2 wings (80 UE aircraft) of B-58 medium bombers
1,500	for 2 XB-70 test aircraft
2,800	for the fleet of 43 squadrons of KC-135 tankers, used for aerial refuelling of the B-52 and B-58 forces
1,100	for the Quail decoys and the Hound Dog air-to-surface missiles used to aid the B-52's penetrate to targets
5,400	for 13 squadrons of Atlas liquid-fuelled missiles
5,700	for 12 squadrons of Titan liquid-fuelled missiles
7,100	for 16 Minuteman I and 4 Minuteman II squadrons, comprising 1,000 missiles, funded through the fiscal year 1965. The Minuteman force to be achieved by 1969, including retrofit, is estimated to cost $11,100 million
10,300	for the fleet of 41 Polaris submarines and their support ships

Countermeasures

72. Countermeasure costs for missiles are considered to be associated with the deployment of an ABM system and reactions to ABM deployments. In the United States, the Nike-X system, consisting of both area and point defences, has been under development for several years. The acquisition costs of the Nike-X system will depend on the extent to which it might be deployed. Estimated costs range from approximately $4,000 million for a light deployment against a limited threat, to upwards of $40,000 million for a full deployment against a sophisticated threat employing a variety of penetration aids. To be fully effective, an ABM system must be supplemented by a civil defence programme, providing fallout shelters. The cost of such a programme is not included in the above figures. Penetration aids are designed to increase the effectiveness of attacking forces against targets defended by ABMs. The United States has spent over $1,200 million on research and development in this area. Deployment of these devices will entail additional costs.

PROCUREMENT COSTS SUMMARY

Modest nuclear capacity

73. As a frame of reference, it has been assumed that a credible but modest nuclear capability could comprise a deliverable warhead and an elementary delivery system, including intermediate-range missiles and some aircraft. The assumed force is made up of the following units:

Thirty to fifty bombers of the Canberra or B-57 type, purchased abroad;

Fifty medium-range missiles of the 1,500 n.mi.-range in soft emplacements, developed and produced indigenously;

One hundred nuclear weapons, developed and produced indigenously.

74. According to the previous tables 7 and 9, the total minimum cost of acquiring such a force deployed over a ten-year period would be $1,700 million, which can be broken down as follows (in millions of US dollars):

	Procurement costs	*Operating costs*
Warheads (100)	200	
Aircraft (30-50)	180	250
Missiles (50)	900	150
TOTAL	1,280	400

75. These rough cost estimates for a modest nuclear force have been based on the scientific, technical and industrial capabilities of a modern industrial nation, which has already a good experience in nuclear power, aircraft and space technology. The costs of such a force would obviously run higher if a domestic industrial base had to be established for the development and production of the delivery system.

76. The above warhead costs are based on the Swedish study (4), which probably covers relatively crude testing of one single type of warhead. An extension of the weapons programme to include production and testing of both strategic and tactical weapons could, using the French programme through 1960 (11) as an example, increase the total costs by some $50-60 million (see also sections on designing and manufacturing and on testing).

Small, high-quality nuclear force

77. A Polish study has been undertaken for the purpose of this report to estimate the costs of a small, high-quality nuclear force (48). A programme comprising two stages of five years' duration has been envisaged. By the end of the first stage (1968-1972) a nuclear force of from ten to fifteen bombers and from fifteen to twenty nuclear weapons would be established, and during the second stage (1973-1977) the force would be extended to include from twenty to thirty thermonuclear weapons, 100 intermediate-range missiles and two missile-launching nuclear submarines. The total costs of this programme based on domestic industry and home economy resources would amount to $5,600 million, resulting in average annual costs of $560 million.

78. The pictured Polish programme (48) is a scaled-down version of the French programme (48). The cost estimate is considerably lower than the apparent expenditures in France and the United Kingdom, both of which are in the course of establishing high-quality nuclear forces of moderate size.

79. French costs for the military nuclear programme to 1969 have been estimated at $8,400 million (11), and the United Kingdom cost to 1969 at a similar amount.[e]

80. Annual outlays of $50 million were representative of the early French programme, but these later rose to as much as $1,000 million for a single year.

81. The actual annual costs of the nuclear forces in some countries are shown in table 10. The costs are also given relative to the annual defence budgets and GNP.

82. Comparison of the figures given in table 10 should be made with caution, partly because they refer to countries at different stages of nuclear weapons development, and partly because the size of the respective nuclear forces is not known.

ALLOCATION OF RESOURCES

83. If the capacity to produce a nuclear force is to be developed indigenously, and this is assumed to be the objective, the materials and manpower requirements represent not only major financial outlays but, more significantly, very highly specialized resources. Even for an industrialized country, the economic difficulties are likely to be more formidable in these terms than in money terms (46).

84. The available public literature on nuclear weapons development does not detail the resource requirements for the acquisition and operation of a military-

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[e] The United Kingdom costs are not strictly comparable, since three bomber types were developed, procured and deployed over a longer period.

TABLE 10. ACTUAL COSTS OF NUCLEAR FORCES

Country	Period of time	Total costs (in $US millions)	Annual costs as percentage of	
			Military budget	GNP
France	1960-1964	2,400	13	0.7
	1965-1970	5,200	18	0.9
United Kingdom	1962-1963	480	10	0.7
	1965-1966	350	6	0.4
	1966-1967	300	5	0.3
United States	1962	13,200	26.4	2.4
	1963	12,100	23.3	2.1
	1964	11,200	21.1	1.8
	1965	8,200	16.8	1.3
	1966	8,200	14.6	1.2
	1967	8,400	12.1	1.2

significant capability. There are, however, numerous references suggesting the variety, kind and quality of resources needed.

85. For a nuclear weapons programme, the basic ingredients are raw materials, a corps of skilled engineers and expert physicists and a modern industrial base (47). Sophisticated delivery systems are equally demanding of high-quality materials and skills.

86. A study of the number of scientific and technical personnel required by a nation to build installations in which nuclear warheads could be produced on a continuous basis has estimated that approximately 1,300 engineers and 500 scientists would be needed.

87. For production of intermediate-range ballistic missiles, estimates suggest that manpower requirements for technical and skilled personnel would run higher than those for nuclear weapons. To produce and deploy fifty missiles of the intermediate-range size, it is estimated that a peak labour force of 19,000 would be needed, over 5,000 of them scientists and engineers. Skill categories would include physicists, aerodynamics, mechanical and other engineers and large numbers of skilled production workers, including machine operators and welders.

88. The assumed bomber fleet would require at a minimum 1 or 2 million or more engineering man-hours of skilled and unskilled labour just to assemble. The design and development stage would absorb an additional 2 million or more engineering man-hours, which would involve highly skilled efforts in aerodynamics, stress analysis, design work and flight-testing.

89. For the development of the Swedish AJ 37 Viggen attack-fighter the peak manpower efforts in 1966 amounted to a total of 2,500, including 200 scientists. At a production rate of, for example, thirty-three planes per year about 4,000, including 400 scientists and engineers, will be employed in the production.

90. For most countries becoming a nuclear power, the costs of allocation of resources would be more significant than the financial costs, and considerably more difficult to detail and evaluate. Neither is a "bill of goods" available for the assumed nuclear capability; nor are adequate data available to show national capabilities in the types of specialized, high-quality resources required by nuclear programmes.

91. The manpower requirements given above for developing and manufacturing fifty bombers and for designing, building and deploying fifty missiles correspond roughly to 7,000 scientists, engineers and technicians. This number of

specialists would represent a large percentage of all scientists and engineers available in many countries.

92. The establishment of the nuclear force envisaged in the Polish study would require that almost the entire corps of scientists, engineers and technical personnel assigned to the peaceful uses of nuclear energy, as well as nearly all nuclear-equipment-producing industries in Poland, would be absorbed by the weapons programme. Additionally, the most highly qualified fraction of all scientists, engineers and technicians available and a major fraction of, for instance, the chemical, metallurgical and electronics industries would have to be allocated to the weapons programme.

Economic implications

93. The derivation of the data presented in the graph in figure VIII of section II of the report is explained below, and the actual values plotted are given in table 11.[d]

94. The United Nations *Statistical Yearbook, 1965,* table 192, presents for a large number of countries reported expenditures by central and regional governments in several fields. For most countries, expenditures on defence, education and health appear as separate items. The amounts are there quoted in national currency units. They have been converted to equivalent United States dollars using rates of exchange quoted in table 185 of the same *Yearbook*. Where rates of exchange have varied, a selected mean figure has been used. The year 1964 was selected as the latest for which most reports appear. Where the most recent information was for another year, that is indicated in table 11. Where there is no report for any item the country is omitted from that list. It may be observed from the lists that the items are incomplete for two major countries, France and Italy, and this in the graph in figure VIII of the report causes some displacement to the left of the lines for health and education. The lack of information from smaller countries has negligible effect.

95. In the graph, horizontal lines are drawn corresponding to the two illustrative expenditures of $170 million (US equivalent) per year for a modest nuclear force, and of $560 million per year for a small high-quality force. The graph shows that these levels would represent a very large component of the total defence expenditure for all except about the ten largest, that is, six countries beyond the existing nuclear-weapons Powers. About twenty countries have higher total defence expenditures than that for the modest nuclear armament of $170 million per year.

96. It thus appears that there are only about six countries in the world, other than the five nuclear-weapon Powers, that could contemplate an added expenditure of $170 million a year to develop a modest nuclear armament without reallocating a major part of their technical resources from constructive activities. For the small nuclear capability suggested costing $560 million a year, only the six appear capable of finding the necessary resources.

97. What may be derived correctly from the graph is an appreciation of the relative magnitude of the expenditure on a nuclear force compared with other government expenditures on defence, education and health. Any further deductions from the graph should be made with caution, for it must be remembered that accounts are not kept in the same way and rates of currency exchange vary. Moreover, what are reported are central and regional government expenditures, and in many countries education and health are to a considerable extent financed otherwise.

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[d] The form of presentation of the statistical data was decided by the consultant expert group.

TABLE 11. NATIONAL EXPENDITURES IN EQUIVALENT UNITED STATES DOLLARS

	Defence				*Education*			*Health*	
Year	$ *millions*	*Country*	*Serial No.*		$ *millions*	*Country*		$ *millions*	*Country*
1964	54,514	USA	1		35,528	USA		40,836	USA
1964	14,765	USSR	2		16,106	USSR		20,339	USSR
1964	5,615	UK	3		4,346	UK		3,231	Germany, F.R.
1964	4,016	Germany, F.R.	4		2,250	Germany, F.R.		3,138	UK
1964	3,891	France	5		2,003	Italy		1,207	Australia
1964	1,702	India	6		1,820	Canada		838	Poland
1964	1,568	Canada	7		1,033	Japan		415	Canada
1964	1,467	Italy	8		1,008	Netherlands		245	India
1964	924	Poland	9		1,002	Poland		183	Denmark
1964	774	Sweden	10		736	Belgium		173	Sweden
1964	734	Netherlands	11		582	India		172	Venezuela
1964	539	Australia	12		572	Sweden	(1963)	165	Brazil
1964	496	Belgium	13		468	Australia		163	New Zealand
1964	443	Yugoslavia	14	(1963)	373	Brazil		136	Argentina
1964	427	Japan	15		301.5	Mexico	(1963)	128	Bulgaria
(1963)	369	Spain	16		273	Finland		107	Finland
1964	340	Switzerland	17		262	Argentina		73	Yugoslavia
1964	320	Turkey	18		243	Denmark		64	Mexico
(1963)	314	Brazil	19	(1963)	221	Bulgaria		60.6	Turkey
1964	302	Argentina	20		219	Turkey		53.8	Peru
1964	267	UAR	21		217	Austria		50.8	UAR
1964	250.5	Israel	22	(1963)	205	Spain		47.5	South Africa
1964	241	Pakistan	23		174	Venezuela		42	Belgium
1964	235	Denmark	24		164	Norway		38.6	Israel
(1962)	220	Bulgaria	25		149	Philippines		37.9	Norway
1964	208	Norway	26		140	UAR		36	Netherlands

TABLE 11. NATIONAL EXPENDITURES IN EQUIVALENT UNITED STATES DOLLARS
(*continued*)

Defence					*Education*			*Health*	
Year	$ *millions*	*Country*	*Serial No.*		$ *millions*	*Country*		$ *millions*	*Country*
1964	193	Iran	27		115	New Zealand	(1963)	35.7	Nigeria
1964	188	Greece	28		115	Peru		26	Pakistan
1964	176.3	Portugal	29		110	Chile		21.2	Thailand
1964	165	Indonesia	30		107	Yugoslavia		14.1	Portugal
1964	160	South Africa	31		105	Thailand		11.1	Austria
1964	144	Venezuela	32		94.6	Israel		6.0	Indonesia
1964	132	Austria	33	(1963)	89	Nigeria		3.7	Switzerland
1964	130	Mexico	34		75.1	South Africa			
1964	130	Finland	35		70	Pakistan			
1964	94.1	Thailand	36		42.3	Portugal			
1964	78.5	Chile	37		41.1	Switzerland			
1964	78.2	Peru	38		14	Indonesia			
1964	77	New Zealand	39						
1964	76	Philippines	40						
(1963)	53.3	Nigeria	41						

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