Item 3. (a) of the provisional agenda.

THE QUESTION OF NUCLEAR EXPLOSIONS FOR PEACEFUL PURPOSES BY NONNUCLEAR-WEAPON STATES AND THE POSSIBILITY OF MISUSE OF SUCH TECHNOLOGY FOR THE PRODUCTION OF NUCLEAR WEAPONS

by

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1. Terms of reference

This paper deals with "the question of nuclear explosions for peaceful purposes and the possibility of misuse of such technology for the production of nuclear weapons", an item on the provisional agenda of the Conference of Non-Nuclear Weapon States (A/617).

2. General remarks

The specific misuse referred to above is discussed as one of the possible misuses of peaceful nuclear explosions. These are discussed against the background of conditions that have to be satisfied to permit the non-controversial international exploitation of peaceful nuclear explosions. The technical, radiological and economic conditions for peaceful explosion uses have in the past been much investigated, and great advances have been achieved. It is only in the last years that these developments, together with developments in the field of disarmament and arms control, have created opportunities for the study of other conditions for the proper peaceful use of nuclear explosions. The writer has therefore made an effort to consider also conditions other than purely technical, economic and radiological ones.

The political context of the international exploitation is first taken to be the present situation, with the partial test ban treaty and the Latin American nuclear free zone treaty. Secondly, the situation created by the non-proliferation treaty is discussed. The situation with an eventual complete test ban treaty is discussed as a third alternative.

3. General nature of peaceful applications of nuclear explosions

This paper was written on the assumption that the large, and in some ways unique, benefits that can ensue from peaceful nuclear explosions will be fully explained elsewhere. They fall into three main categories: scientific applications, economic exploitation of natural resources and large earth excavations. For the purposes of this introduction it is sufficient to describe only briefly the experienced or envisaged applications of such explosions.

1/ See, for example, the paper by C. Gerber, "Industrial and Scientific Applications for Nuclear Explosions", *Journal of the British Nuclear Energy Society* (January 1967).
4. Scientific uses

The experience with scientific applications (such as use of the intense neutron burst from nuclear explosions for studies of the nuclear properties of matter or for the production of new elements and also the use of the energetic pressure pulse from such explosions for world-wide studies of the interior of the earth) has already well proved the unique scientific values of such applications.

Further uses of this kind should present somewhat special problems for non-controversial international exploitation, problems which probably are best solved on an ad hoc basis, after establishment of some general agreement on the desirability of such undertakings and some basic procedure for international exploitation. This relative simplicity would be due not only to the peculiar nature of the scientific uses of nuclear explosions but also to their economically and logistically limited size.

5. Exploitation of natural resources

Nuclear explosions for the exploitation of natural resources have been deemed to offer, in some cases, economically attractive alternatives to the conventional exploitation of water, natural gas, oil and ores. Some of these appear as more than marginal alternatives to conventional techniques. They seem to offer unique methods to exploit otherwise practically inaccessible resources and have therefore a potentially great and widespread importance. The current joint efforts of authorities in the United States and private enterprises there in a practical test of the feasibility of natural gas extraction by nuclear explosions are expected to give important technical and economic experience. It seems to the present writer that the legal and political experience from this venture will also be of great interest, even if limited to the domestic conditions in the United States.

National or international exploitations of natural resources by nuclear explosives would be of sufficient technical and economic size to present also considerable health, legal and political problems specific to the peculiar nature of nuclear explosives. Their possibly widespread application to the exploitation of natural resources hence warrants close study of all the problems involved.

6. Nuclear excavation

The use of underground nuclear explosions for large earth moving or excavation works (making harbours, canals or dams) obtains its economic attractions partly from the relative ease of handling of such explosive charges but mainly from the very low price at which explosive energy can be had from powerful thermonuclear charges. At the present stage of technology this last advantage is contingent on the nuclear explosives being obtained at only marginal cost from very large basic investments for military purposes. There are, of course, several drawbacks. One is the present economic limitation to very powerful explosions, with ensuing limitations of technological flexibility and with increased problems of seismic or atmospheric damage to adjacent property. A more obvious drawback is the special requirement to avoid radiological health hazards. The products of chemical explosions are so much more congenial to biological life than radioactive substances, that they present almost no problems at all. Finally many political and emotional problems are involved in the peaceful use of nuclear explosives.

The economic attractiveness of nuclear explosives for excavation is at present confined to large or very large projects, projects for which the term "geographic engineering" is appropriate. International undertakings of that kind can easily be so large that they present major problems even without the added complication of nuclear explosives.

The obvious example here is the project for a new Atlantic-Pacific canal. The change of conditions such a canal could make would not only give large general benefits but would also generate a host of economic and political problems both in the national and the international sense. It could well be that the considerable economic advantage predicted for nuclear instead of chemical excavation (of the order of thousands of millions of dollars) will turn out to be only marginal relative to the importance of other aspects of the project.

In any case large international excavation projects do require extensive and time-consuming preparations. The possible use of economic nuclear explosives would not lessen this need; on the contrary, the specific nuclear aspects will require additional care, not only in preparations but in the final decisions.

B. TREATY BACKGROUND.

1. Partial test ban treaty

The partial test ban treaty (ENDC/100/Rev.1) limits the nuclear explosions permitted to its parties to contained underground explosions\(^4\) or to such venting underground explosions\(^5\) where no radioactive debris or fallout leaves the territory of the testing party.

There are no arrangements for international control in this treaty.

2. The treaty for the prohibition of nuclear weapons in Latin America

This treaty (ENDC/186) has in its article 18 rules for how and on what conditions a party to the treaty can use or participate in nuclear explosions for peaceful purposes.

The procedure involves participation of the agency of that treaty, with a control system (article 12) working in co-operation with the International Atomic Energy Agency. Observation of peaceful nuclear explosion work by the International Atomic Energy Agency is specifically arranged for.

The conditions are observance of articles 1 and 5 of the same treaty. Article 1 prohibits any direct or indirect testing, use, manufacture, production, acquisition, receipt, storage, installation, deployment and possession of nuclear weapons. Article 5 then defines a nuclear weapon as any device capable of releasing nuclear energy in an uncontrolled manner and which has a group of characteristics appropriate for use for warlike purposes. A not indivisible and separable instrument for the transport or propulsion of such a device is not included in the definition.

The treaty also has provisions for dealing with problems of interpretation etc.

3. Non-proliferation treaty

The present proposals for, and discussions of, a non-proliferation treaty (ENDC/225) aim at halting the further spread of nuclear weapons. Nuclear-weapon States parties to the treaty would be obliged not to transfer nuclear weapons or nuclear explosives out of their control (article I) and non-nuclear-weapon States parties to the treaty would be obliged not to make or acquire nuclear explosives or weapons (article II).

In order to make the benefits from any peaceful application of nuclear explosions available to non-nuclear-weapon States parties to the treaty, the treaty also obliges all treaty parties to co-operate in international procedures to make the benefits available at low cost (no charges for research and development) and on a non-discriminatory basis. The benefits would be obtainable either bilaterally or through some international organization representing also non-nuclear-weapon States (Article V).

\(^4\) Where no radioactivity is released to the atmosphere.

\(^5\) Releasing some radioactivity to the atmosphere.
In the discussions preceding the present proposal it was suggested that the detailed arrangements for the exploitation of peaceful nuclear explosion should be made in a separate treaty or agreement.

4. Complete test ban treaty

A complete test ban treaty would require its parties to abstain from underground explosion testing of nuclear weapons.

If peaceful nuclear explosions shall be permitted under such a treaty, then the problem of how to avoid prohibited weapons testing must be solved. The question of how peaceful nuclear explosions could be politically accommodated in a complete test ban case has already received some discussion. Later in this paper we will consider technical accommodation problems.

6. CONDITIONS FOR THE NON-CONTROVERSIAL EXPLOITATION OF PEACEFUL NUCLEAR EXPLOSIONS.

For the non-controversial exploitation of peaceful nuclear explosions several conditions have to be satisfied, whether the exploitation is national or international. This section is an effort to present a collection of such more or less obvious conditions. They are not fully discussed. In some cases conceivable solutions or arrangements are mentioned. A full discussion of them would be best done in relation to some specific project.

1. Technical feasibility

The most obvious requirement for non-controversial use is technical feasibility. The project must have a certain expectation of achieving its purposes within acceptable limits: the excavation should have a diameter and depth within required numerical limits etc. These are technical problems to be solved on the basis of past experience, of thorough investigations of the conditions of the specific project and of extensive calculations. For very large or critical projects off-site or on-site test explosions or other special developmental work will be necessary. For international exploitation the legal aspects of the responsibility for feasibility are of special interest. Feasibility will, of course, also be of primary importance for the financial support of the venture.

2. Economic advantage

For developmental or pilot projects, like the recent Gasbuggy explosion to extract natural gas, cost will be of secondary importance. In purely commercial projects, however, the cost of nuclear explosives, of their emplacement and of the special measures against health hazards will have to meet not only the condition of absolute commercial
feasibility but that of advantage over other techniques. The nuclear advantage will have to be clear, because in marginal cases the non-economic complications of nuclear operations will favour other techniques.

In projects large enough to effect a whole nation the immediate economic advantages or disadvantages of the project itself will have to be measured also against the national interest as a whole.

3. Health physics requirements

The project will have to meet international and national standards for acceptable radioactive contamination of the human environment and similar radiation standards for employed personnel and people in general. This means that the expected radiation hazard situation after the explosive work, as foreseen before that work, will have to show a very high degree of assurance of coming within acceptable health physics limits. The expected levels have to be safe, and the variability of the expectation has to be low. Such requirements call for sufficient previous experience, for thorough investigations of the specific project and for wide safety margins in the nuclear operations.

During the preparatory stage of a project and during the nuclear operation an extensive environmental investigation and control will be required. For identification of hazards, if they should occur, extended follow-up work will also be required.

For such control and monitoring of possible nuclear health hazards a special organization within the project will be necessary, separate from the body, with responsibility to set safe but reasonable radiation standards. Questions of responsibilities again arise, especially in the case of international co-operation.

4. Other safety requirements

The employment of very powerful explosive charges will, of course, generate special arrangements to avoid accidents during the handling of the charges. In addition, incidental damage to property from the projected explosions will have to be foreseen and avoided or paid for in an acceptable manner. In both cases, questions of damage assessment and responsibility have to be settled beforehand.

5. Environmental considerations

Apart from the hazards from the introduction of radioactive substances into the environment, discussed above under health physics requirements, large engineering works can generate considerable environmental changes. Examples are changes in the distribution of underground water to man, beast and vegetation or the disruption of ecological complexes used for agriculture or fishery. Undesirable changes of this kind will have to be foreseen and assessed and ways of settlement arranged. These problems are not specific to nuclear explosions; they are present in all large undertakings of geographical engineering.
6. Peaceful ends of the specific project

For the non-controversial international exploitation of peaceful nuclear explosions the result of the exploitation will have to be peaceful in itself.

Most civilian assets of a nation can also be of indirect or direct military use. In case of international mistrust, any improvement in the economic position of one party can be interpreted by the other party as a threatening development.

7. Proper treaty observation

States involved in peaceful exploitation of nuclear explosions will be obliged to observe relevant treaties, such as the partial test ban treaty, probably a non-proliferation treaty and also treaties or other commitments more specific to the States involved, such as nuclear-free-zone arrangements or other special agreements bearing on nuclear explosives or weapons. In the case of international co-operation, the situation for the participants could easily by asymmetric.

In cases of mistrust, or as a precaution against such attitudes, international supervision of proper treaty observance seems to be the remedy. For the specific problems of assuring that forbidden nuclear measurements are not made, as discussed below, special expertise will be required.

In the present paper the observance of general treaties on test ban and non-proliferation is the primary issue. Special problems of specific countries are not discussed. It is also assumed that national rules for the handling of atomic energy affairs will be nationally amended as required.

8. Isolation from disturbing international issues

The States able to make nuclear explosions for the use of their own or of others are generally influential in other spheres and involved in dominating political issues. International co-operation for the peaceful exploitation of nuclear explosions will be a complex matter, and, in most cases, it also will be a fairly large undertaking, with the need for close governmental, economic and technical co-operation. Even if very desirable for the specific economic or scientific purpose such co-operation could, in some cases, appear objectionable to one or both parties because of the possible entanglement with problems outside the peaceful nuclear explosion project itself. Difficulties of this kind could then hinder worthwhile projects and even exclude some parties from having non-controversial access to benefits from peaceful nuclear explosions.

The solution to this problem with the arrangement of non-controversial international peaceful exploitation of nuclear explosions seems to be the use of an international expert organization as an intermediate. There have been several suggestions for the employment of such an organization for this and for other related purposes.
The problems referred to above are not confined to the nuclear operations, and an international agency would have a rather complex task, requiring expertise in nuclear science, nuclear operations, explosion physics, various engineering branches, economics, health physics, environmental geography and biology, international law etc.

9. **Prevention of non-rational fears or accusations**

Even after an effective arrangement for some economic, safe, peaceful, treaty-abiding, and, on the governmental level, non-controversial use of nuclear explosions has been arrived at, there will remain the need to prevent non-rational beliefs of nuclear explosions as evil, fears of radioactivity as a menace of non-rational accusations of nuclear weapons spread or nuclear weapons tests despite sufficient control. Experience from the siting of nuclear reactors and from other nuclear operations has shown these to exist. The probability of such difficulties is increased in the case of nuclear explosives, which are close to all the emotional issues surrounding nuclear weapon tests, nuclear weapons and nuclear weapons policy. Thus a disturbed public opinion could well become a serious problem, despite its non-rational basis.

Past experience with the siting of nuclear reactors and with nuclear test explosions has shown that domestic apprehensions among the general public can be prevented by the systematic dissemination of authoritative information on all aspects of the problems envisaged by local authorities and by the general public, provided that the nuclear project itself is sound. Such measures should be efficient also for peaceful nuclear explosions. In the case of international exploitation this problem would be increased, calling for extended informative preparations.

**D. MODES FOR THE PROVISION WITH NUCLEAR EXPLOSIVES**

1. **Alternatives**

Nuclear explosives for peaceful purposes could be obtained in three ways:

(a) Countries producing military explosives would have facilities to satisfy their own needs as well as the needs of others;

(b) Non-nuclear-weapon countries could set up peaceful production facilities of their own;

(c) Countries could co-operate in a common production facility for peaceful purposes.
At the present stage of technology the second alternative, with national production for peaceful purposes, would make the peaceful nuclear explosive charges very expensive, when compared with the relatively low marginal cost at which they can be obtained from large investments for military purposes. This would obviate the main advantage of nuclear explosives for peaceful purposes: the low cost per unit of explosive energy. Objection to this national alternative would, of course, disappear or become weaker if much cheaper production methods are found in the future.

In any case, a second objection to this national alternative remains. The basic aims of the widespread efforts to slow down or to halt the proliferation of nuclear weapons would be counteracted. This is so because peaceful nuclear explosives and military nuclear explosives are obtained from the same kind of know-how and production facilities. In addition, the attainment of know-how and the setting up of production facilities is an expensive and time-consuming task, constituting a main part of a nuclear explosive programme, whether for military or peaceful purposes. An eventual step from peaceful production to military production would therefore be greatly speeded up and facilitated by the setting up of such facilities, even if additional efforts for weapon-delivery vehicles etc. were required. The mere existence in unforeseeable future circumstances in non-nuclear-weapon countries of production facilities for nuclear explosives would thus constitute a destabilizing feature very undesirable to many in a non-proliferation treaty, even if there is no intention at all to make anything but peaceful explosives.

The third alternative, with international co-operation in the production of peaceful nuclear explosives, would give the economic advantage of distributing the basic cost over several countries and thus making the explosives cheaper. But here, too, the objection about destabilized non-proliferation arrangements applies if a group of non-nuclear-weapon countries co-operates. The alternative, with a completely international organization, presents similar political difficulties. It would also be hard to get ready-made expertise, and it would be time-consuming to build up expertise. It would be complicated to find territory to operate on and difficult to maintain the secrecy necessary against improper spread of nuclear weapons know-how. This alternative seems at present to be too difficult. Perhaps at some future stage a closer investigation of the practical possibilities will be more worthwhile.

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7/ The basic cost of nuclear explosives production for military purposes can be estimated from data in Effects of the Possible Use of Nuclear Weapons and Economic Implications for States of the Acquisition and Further Development of These Weapons: Report of the Secretary-General (United Nations publication, Sales No.: E.68. IX. 1).
2. **International peaceful nuclear explosion services by nuclear weapon States**

To overcome the difficulties mentioned above and to make the peaceful exploitation of nuclear explosives available to all countries, efforts have been made in the preparations for a non-proliferation treaty for a solution according to the first alternative above. In the proposed non-proliferation treaty the peaceful use of nuclear explosions is allowed for,\(^8\) and a detailed arrangement of the matter in a separate treaty has been suggested.\(^9\)

This solution essentially means that nuclear-weapon States would provide a peaceful nuclear explosion service on equitable terms.

An envisaged service has been sketched in some detail.\(^{10}\) The State performing the service would carry out the desired nuclear explosion under international observation, with the nuclear device remaining under the custody and control of the State providing the service. Non-nuclear-weapon States desiring nuclear explosive service could procure it, if they wish, through an international body in which they participate. This body could also deal with feasibility, priorities and safety. The body could also act as a contracting agency on the governmental level. The cost of services by nuclear-weapon States would be kept as low as possible and would not include research and development. There would also be readiness for full consultation among concerned parties about required limited test ban amendments. Finally there would be readiness for full co-operation between nuclear and non-nuclear parties in the development of proper conditions and procedures for such services.

There have also been more or less detailed suggestions as to how this might be carried out in practice, suggestions dealing mainly with political issues.\(^{11}\)

Here it should be added that the inter-State arrangements are foreseen to be exclusively at the governmental level for basic arrangements and with designated State agencies for performance of the nuclear part of the international co-operation. This would be similar to present arrangements for international co-operation for the use of reactor fuels. The nuclear operations would thus not be let out of State control, even

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\(^8\) ENDC/225.

\(^9\) ENDC/PV.293 (USSR) and ENDC/PV.295 (USA).

\(^10\) ENDC/PV.295 (USA)

\(^11\) ENDC/PV.302 (Sweden) and ENDC/PV.329 (Canada).
if is to be expected that private engineering enterprises will be interested in providing, to the Government concerned or to its agents, their services for many of the other tasks involved in peaceful domestic or international uses of nuclear explosions.

This foreseen division between activities controlled and performed by States and activities controlled by States but performed by others arises out of the intention that the basic international explosion service will be confined to the making of the explosion. This will then be the basic object for international or interstate co-operation. Preparation of the site and exploitation of the explosion effects will be the task of the customer State and carried out at its discretion by the customer State or its agents. It is, however, clear that arrangements for safety and security and provisions for the required international observation or control are other likely tasks well suited for international co-operation.

E. NUCLEAR OPERATIONS FOR PEACEFUL NUCLEAR EXPLOSIONS

By now enough background has been given to provide a proper setting for a description and consideration of the nuclear operations involved in the exploitation of peaceful nuclear explosions.

1. Gasbuggy

In connexion with a recently started study in the United States of the release of natural gas by underground nuclear explosions, the nuclear operation in the project Gasbuggy has been described in some detail.\textsuperscript{12} Gasbuggy is a domestic United States project and involves direct co-operation of the official United States agency for nuclear energy with a private enterprise, on the latter’s property in a project of relatively limited size and in a situation where only the partial test ban treaty applies. The nuclear operation involved is therefore of some interest as an example for the future.

Gasbuggy was an underground explosion of about 26 kiloton strength, 1,300 metres down in a borehole and expected to release very little or no radioactivity. The explosion was made after extensive studies and technical preparations by both participants.

\textsuperscript{12} W. Woodruff, "Nuclear Operation: Project Gasbuggy", Report UCRL-50334
Livermore, California (October 1967).
The development of the project consisted of a feasibility study, followed by a development of technical objectives and measurements. These were then submitted to the United States authority concerned, whereupon operational plans were made by the designated governmental technical agents. On that basis budgets were made. After fiscal arrangements a contract was finally negotiated between the United States Government and the private enterprise.

The planning and the design for the operational plan covered the selection of the explosive, according to desired explosive energy, environmental circumstances in the borehole (pressure and temperature), possible dimensions, reliability and compatibility of the produced radioactive debris with the ultimate products (ratio of fission to fusion). The selected explosive was combined with a cooling unit and put into a canister for protection against downhole pressure. For downhole arming and firing a special cable with more than fifty conductors was used. After fabrication and pre-delivery checks the United States agency transported the explosive to the test site in a special truck under security arrangements and with emergency equipment. At the site it was put into a special assembly building.

At the site a carefully cased and cemented emplacement hole 1.3 km deep had been made. Further, an operation control point and a data recording point had been established. Numerous instruments had been placed on the surface around ground zero, in the borehole and in satellite boreholes, with cable connexions to the recording and control points. The control point handled timing and firing, received all remote measurements for safety purposes and monitored all technical programmes.

After an external check-up and radiography for the explosive, the firing and monitoring systems were checked and dry count-down runs made for proper adjustment of all electrical systems.

After these check-ups, the explosive was pre-armed by final electrical connexions, with the surface end of the firing cable locked. Then the explosive and the cooling unit were put into the canister and sealed.

For emplacement into the hole (a two-week job) a mobile crane took the explosive assembly (one ton, 5 m long and 55 cm in diameter) to the emplacement hole, where an oil drill rig lowered it together with the arming and firing cable. After another downhole electrical check, careful stemming started, mainly with grout and up to the surface. The top end of the cased hole was then sealed. Satellite boreholes nearby were also stemmed.
After reviewing the advisability of proceeding with an advisory panel of experts in meteorology, radiation safety and operational control, the test manager cleared the area of all unnecessary personnel, and the explosive was armed. With the electrical stems of the timing and firing unit at the control point locked out, the downhole mining and firing cable was connected to the surface cable from the borehole to the mining and firing unit. After another check-up of conditions count-down towards the ring was started.

After the explosion, the safety monitoring displays were used to decide whether radiation conditions and the cessation of underground cavity formation permitted hazards control personnel to make a direct check at the shot site that no radiation hazards existed. Thereupon personnel concerned with technical measurements was admitted to the site to retrieve data. Post-shot drilling activities etc. were permitted only after the completion of the immediate data retrieval.

The post-shot drilling is carried out to explore the cavity produced, to measure and sample the natural gas released and to obtain samples of radioactivity for off-site study of the produced radioactivity and of its containment or spread.

The number of personnel involved in routine nuclear operations of approximately is size has been estimated to be about twenty people for administration, for handling the explosive and for firing.13/ Personnel for data recording would depend on the count of data taken and could involve between ten and twenty people.

This somewhat lengthy description gives a picture of the on-site nuclear operations a small project for the peaceful use of a nuclear explosion, a picture that is useful for later discussion of the conditions for observation or control in order to ensure easy observance.

The Atlantic-Pacific canal

A picture of the nuclear operations in a very large project can be obtained from description of the nuclear operations envisaged in an older study of nuclear operations in a nuclear excavation for a new Atlantic-Pacific canal.14/ That study

/ R. Adelman, "Field Operations with Nuclear Explosives", a course on nuclear explosions for excavation and construction, University of California, Berkeley, 1960 (lecture notes by the present writer).

considered the use of about 300 nuclear explosive charges with a total yield between 7 and 35 megatons, fired in about eighteen explosions distributed over about two years.

The nuclear operations were envisaged as being the responsibility of a nuclear operations manager, under the over-all canal project management. In detail the nuclear operations manager had responsibility for:

(a) Operations co-ordination and area control;
(b) Explosives security;
(c) Nuclear explosives operations;
(d) Meteorology programme;
(e) Radiological safety and terrestrial environment programme;
(f) Marine environmental programme;
(g) Air blast prediction and evaluation programme;
(h) Seismic effects prediction and evaluation programme.

The work was envisaged to be distributed over a survey phase of three years, a technical preparations phase of one year, an explosion phase of about two years and a post-explosion phase of about five years. The on-site personnel requirements for management, scientific and technical staff and for their close support in these nuclear operations were estimated to be about 150 people during the survey and technical preparation phases, 1,100 people during the explosion phase and about 250 in the post-explosion phase.

In the present context the envisaged arrangements for operations co-ordination and area control, for explosives security and for nuclear explosives operations are of special interest.

The purpose of the operations co-ordination would be to avoid interference between groups and to achieve compliance with plans. The area control would see to air traffic exclusion and safety, would control closely the clearance of, and access to, the explosive operations area, would survey, in co-operation with a locally recruited guard force of about 160 people, the maintenance of a larger outer evacuation area and be ready to exercise control over accident areas in case of need.

The explosive security organization would safeguard the nuclear explosives taken into the explosive operations area, including the associated secret documents, and it would clear the area of unauthorized personnel at explosion time. In this case of explosions with surfacing or venting radioactivity, the organization would also control for about three months an area of classified debris closest to shot points (this fresh
debris would contain information about the composition of the explosive and could be regarded as secret by the sponsor). In this case of a large and extended project, the explosive security personnel during the explosion phase was envisaged to consist of about 500 citizens of the sponsor State; in the post-explosion phase considerably less.

The nuclear explosives operations would transport, store, handle, emplace, arm and fire the nuclear explosives. During the explosive phase the amount of personnel was foreseen to be about eighty citizens of the sponsor State. Their activities would be essentially as described above for the Gasbuggy project.

The radiological safety and terrestrial environment operation would be concerned with ecological evaluations and safety against radiation hazards. The technical staff personnel would range from 15 to 100 over the operational phases. It would perform extensive radiological sampling. Sampling from the temporary classified debris area would present special security problems to the sponsor.

F. THE DEVELOPMENT AND PRODUCTION OF NUCLEAR EXPLOSIVES FOR PEACEFUL USES

In the previous section peaceful nuclear explosive operations were described, in which suitably selected and modified nuclear explosives are used in an elaborate emplacement and firing technique. Such options and arrangements help to obtain safety, reduce nuclear radiation hazards and aid proper technical execution of the project and economy. The basis for such advantages in the execution of peaceful nuclear explosions is the extended research and developmental work done in the past in order to obtain a wide spectrum of different nuclear explosives, with their associated equipment. The research in question has covered a wide range of management, planning, theoretical work and laboratory and field experiments, including explosive testing.

The main part of this research and development has been for military purposes but special research and development has also been done to obtain explosives with properties especially desirable for peaceful purposes. Such properties would include insensitivity to the often hostile underground environment; very limited size, in order to fit into not too expensive boreholes; and options for a variety of fission to fusion ratios in the explosive process, in order to diminish, if necessary, nuclear radiation hazards and other contamination from the fission part of the explosion energy. In some cases, the amount of neutrons emitted from fusion energy release would have to be designed after prescription. All this has to be achieved together with a general standard of reliability and low cost. The explosive properties desirable for peaceful
applications thus call for rather advanced explosive designs. Some of the requirements are not very different from those for advanced military nuclear explosives, even if the environmental requirements and the handling and firing requirements are somewhat different.

If a research development programme were undertaken to achieve this background again or to improve it solely for peaceful applications, it would not be very different in size and kind from a development programme to obtain nuclear explosives for nuclear weapons. The main difference would be that the explosives design problems connected with the adaption to military weapon delivery systems would be absent. As far as production is concerned, it is hard to see any difference at all between an explosives production facility for peaceful and one for military purposes. The main difference would be the absence, in the peaceful case, of related production of military delivery vehicles and related planning, organizing and instructing of the armed forces.

G. EXPLOSIVE TESTING OF NUCLEAR EXPLOSIVES AND NUCLEAR WEAPONS

In this section an outline of the main purposes of nuclear weapons testing and of essential measurements for such purposes is given as further background material.

The following single or simultaneous purposes with nuclear weapons tests can be envisaged:

(a) Basic development of a nuclear explosive;
(b) Refinement of existing nuclear explosives;
(c) Proof testing of weapons in stock or of factory deliveries;
(d) System tests of the weapon, together with its delivery system;
(e) Training of personnel designated to handle nuclear weapons in war;
(f) Training of supporting troops;
(g) Study of the effects on military targets.

Besides the explosion itself, the attainment of such objectives requires the performance of special measurements, with proper instrumentation, elaborate display of targets and other arrangements of equipment and personnel.

For these reasons we can already at this stage exclude the weapon test purposes (g), (f) and (d), above, from the later discussion of improper weapon tests in connexion with peaceful nuclear explosions. They are easily safeguarded against by observation of the peaceful operation.

In the case of scientific peaceful applications, some difficulties could arise, because some scientifically important geophysical effects are also militarily important (e.g. disturbances of the all-important upper atmosphere for long-range radio communications by high altitude or inner space explosions).
A standard task for test purposes is the determination of yield or energy release of the explosions. This can be done, for fission yield, from radiochemical analysis of the fresh radioactive debris of the explosion and for fusion yield by measuring the emission of high energy neutrons.

Yield can also be obtained from some well-understood effect on the medium around the explosion, like stock-wave velocity etc.

The most essential type of measurement for test purposes, like (a), (b) and (c) above, however, is the detailed diagnosis of the explosive behaviour of the nuclear explosive itself. It would be the essential measurement for basic development, refinement and status check of nuclear explosives, whether for military or peaceful purposes. The main diagnostic tool here is the time-resolved recording of the prompt gamma radiation from the explosion, giving information about the neutron multiplication rate or time-constant alpha in the explosive energy release.

Other essential nuclear explosion diagnostic measurements could be concerned with recording of explosive motion, emission of neutrons and electrons, gamma, Roentgen-radiation, visible light and of radio frequency emission.

The most significant measurement, however, would be the measurement of the alpha referred to above. The equipment for the analysis of this phenomenon, covering a very wide range of values very quickly, requires special gamma transducers at, or close to, the explosive and multiple wide-band signal links to very fast digital or oscilloscope type data recording systems with nanosecond resolution. They would be close to but outside the damage area of the explosions. The measuring system is fairly extensive and a very extreme and specialized kind of equipment.

Similarly fast neutron measurements and other fast emission recording require rather special equipment.

H. STUDY OF NUCLEAR EFFECTS FOR PEACEFUL USES OF NUCLEAR EXPLOSIVES

Besides the design, development and production of the nuclear explosive itself, as described above, the methods for the emplacement of the explosive and the interaction of the explosion with its surroundings is a field for explosive technique development related to, but separate from, the development of the explosive itself. Such developments bear immediately on the desired effects of the explosions, as well as on the control of the release of radioactivity. Several items can be studied:

15/ R. James, "Basic Nuclear Chemistry Concepts", a course on nuclear explosives for excavation and construction, University of California, Berkeley, 1960 (lecture notes by the present writer).

(a) Selection of overburden and yield in various geological settings;
(b) Stemming techniques;
(c) Physical shielding or tampering to control neutron-induced radioactivity;
(d) Chemical tampering to control the containment of fission-produced radioactivity;
(e) Selection of proper fission/fusion energy release ratio, according to the specific demands on the radioactive properties of the end products and for proper economic balance between cheap fusion energy and cost for boreholes etc.;
(f) The physical effects on the immediate surrounding of the explosion, such as making cavities, vaporizing, melting, heating, cracking, cratering and emission of wave motions (these are engineering purposes in themselves but also decisive for the containment or release of radioactivity);
(g) The study of the combined action of items (a) to (f), above (a comprehensive item essential for the development of methods for the peaceful exploitation of nuclear explosions and for the establishment of their practical reliability).

I. ACCOMMODATION OF THE DEVELOPMENT OF PEACEFUL NUCLEAR EXPLOSION TECHNIQUE IN TEST BAN AND NON_PROLIFERATION SITUATIONS

1. Partial test ban treaty

The treaty forbids nuclear explosions under water, in the atmosphere and beyond its limits and thus makes it impossible for its parties to develop peaceful nuclear technique by such explosions. This affects mainly the development of some conceivable peaceful scientific applications in the field of space science and geophysics.

Under this treaty underground explosions are limited to such where measurable radioactive debris or fallout is contained within the national borders of the country conducting the explosion. The stated purpose is to avoid health hazards to other countries. Radioactivity, however, can be measured at levels far below such as have been designed as safe health limits. This stipulation of the partial test ban treaty seriously limits developmental work with venting underground peaceful explosions, such as studied for excavation, and also confines such limited developmental work to the interior of countries with large territories. The development of other underground peaceful nuclear explosion application is not seriously affected.
In order to ensure effective developmental work on peaceful nuclear excavation technique the partial test ban treaty should be amended to allow over-border release of radioactivity within agreed safe health limits. The definition of such limits is well possible. Such an amendment would remove a difficulty generated by the formal simplicity of the partial test ban treaty and could adjust the treaty properly to scientific and technological advances and to political developments.

Such an amendment would not change the present effect of the partial test ban treaty on nuclear weapons development. It should also be pointed out here that such an amendment, of course, would in no way lessen the need for the development of reliable methods to stay within prescribed safe health limits of over-border releases. It would, however, make it much easier to develop this very essential reliability.

2. The treaty for the prohibition of nuclear weapons in Latin America

The treaty specifically provides for peaceful nuclear explosions. The extent to which development for such purposes is possible depends on how its stipulations on separation from nuclear weapons development are interpreted, as given in articles 1 and 5. These prohibit testing of nuclear weapons directly or indirectly and define a nuclear weapon as a nuclear explosive "with a group of characteristics appropriate for warlike purposes".

The Latin American nuclear free zone treaty does not seem to impede the development of peaceful nuclear explosion techniques in the case of co-operation with an outside supplier of nuclear explosive services or to provide against the misuse, by its parties, of such developments.

3. Non-proliferation treaty

The proposed non-proliferation treaty is here taken as applying together with the present partial test ban treaty.

The nuclear-weapon States will not be prevented from, or encumbered in, the development of peaceful nuclear techniques. The present limitation, referred to in section I(1), above, on the effective development of nuclear excavation techniques, however, will remain and apply to them and also to non-nuclear-weapon States.

The non-nuclear-weapon States will not be able to develop peaceful nuclear explosion techniques on their own. They will, however, be free to assist nuclear-weapon States in such developments.

 Assistance in the particular task of development of the nuclear explosives themselves would be formally possible but practically difficult or impossible without great controversy. There would be the argument that the know-how obtained by non-nuclear-weapon States in such assistance would lessen the stability of the non-proliferation treaty in the same way as explained about manufacture in section D(1),
above. The nuclear-weapon States should also be reluctant, because such co-operation could make it hard for them not to disclose some of their secrets.

The non-nuclear-weapon States, however, would be free to assist the nuclear-weapon States in the study and development of the peaceful effects of nuclear explosions, described in section H, above, or to do this on their own. Such study and development does not comprise development of the explosive itself. This field for study and development is major part of the techniques for peaceful use of nuclear explosions and offers many difficult and important scientific and technical tasks. Assistance or co-operation of this kind would also be the best preparation for efficient co-operative applications.

4. Complete test ban treaty

In the case of an underground test ban treaty, in addition to a non-proliferation treaty and a partial test ban treaty amended to allow effective development of nuclear excavation, the main problem concerning development would be to avoid violation of the complete test ban by nuclear-weapon States developing peaceful nuclear explosion methods.

Test explosions for the development of nuclear explosives would be impossible. Development of this kind would be restricted to non-explosive work, such as design. The study and development of peaceful nuclear effects, as described in section H, above, would be possible, provided that the explosions used for this purpose are not explosive test explosions.

Measurements would be concerned with the effects of the explosion, including yield and radioactive debris properties; but diagnostic measurement of the explosive itself would not be possible.

The explosive could be designed or selected by the nuclear-weapon State supplier to be optimal to the purpose. The explosive could also be taken out of a stock under international custody, a possible but somewhat complicated and expensive procedure. It would prevent opportunities for misuse and would not prevent the study and development of peaceful nuclear effects; but it would make the supplier unable to develop explosives desirable or most effective for peaceful uses. A third possibility is to forbid developmental explosions completely.

The author sees the third alternative as disastrous to peaceful applications, the middle one as bearable but rather disadvantageous and the first one as acceptable or advantageous to peaceful applications. The problems of misuse and control will be discussed further below.
J. ACCOMMODATION OF THE APPLICATION OF NUCLEAR EXPLOSION TECHNIQUES TO PEACEFUL PURPOSES IN TEST BAN AND NON-PROLIFERATION SITUATIONS

1. Partial test ban treaty

The conclusions already drawn, in section I(1), above, on the development of nuclear explosion technology for peaceful purposes under the present partial test ban treaty, apply also to the application of such technology. There is, however, one essential difference: the execution of excavation works with nuclear explosives is restricted to small undertakings in the interior of countries with large territories and is difficult even there. Countries with small territories are excluded from the benefits of such technology.

2. The treaty for the prohibition of nuclear weapons in Latin America

The conclusions about applications are the same as in section I(2), above, about development.

3. Non-proliferation treaty

The proposed non-proliferation treaty, together with the present partial test ban treaty, will generally and explicitly permit the use of underground nuclear explosions for peaceful purposes. In the case of nuclear excavation, however, an amendment to permit safe over-border releases of radioactivity will be required to make the benefits of such excavation techniques available to all countries. This point has already been discussed in sections I(1) and J(1), above.

In particular, the non-proliferation treaty will permit international co-operation in the peaceful use of nuclear explosions underground. The non-nuclear-weapon-States parties would, of course, be free to employ the nuclear technology, as described in section H, above, or to assist the nuclear-weapon States therein. The nuclear explosive operations themselves, however, will be limited to the nuclear-weapon States parties to that treaty, acting as suppliers of such explosive services.

4. Complete test ban treaty

In the case of an underground test ban, in addition to the proposed non-proliferation treaty and the present partial test ban treaty amended to allow the use of nuclear explosion for peaceful excavation, the main problem would be to avoid violation of the complete test ban by nuclear-weapon States using or assisting in the use of nuclear explosions for peaceful purposes.

The explosions would be underground explosions. Otherwise another amendment of the partial test ban treaty would be necessary. At present this could be desirable only for some scientific applications. The wide diversity and special character of such applications make it difficult to generalize here on the importance and feasibility of such an amendment.
The same three levels of technical limitations can be discussed for the application of peaceful nuclear explosion technology as above in section I(4) on the development of such technology:

(a) Making the explosions with explosives supplied specially for the particular purpose by the supplier nuclear-weapon State, without essential diagnostic measurements but with measurement of yield, radioactive debris composition and external effects;
(b) Making the explosions with explosives taken out of a stock under international custody, with measurements as in the first alternative;
(c) Not making any explosions at all.

The third alternative is simple. It means that a complete test ban would rule out all peaceful nuclear explosion uses. The second alternative would make it possible to make peaceful applications but not in the most efficient or optimal way. There would also be extra cost and a complicated procedure. The first alternative would permit to make efficient and optimal peaceful applications.

In this case of applications the difference in effectiveness for peaceful purposes between the first and second alternative seems to be somewhat less than in the case of development.

K. MISUSES AND CONTROL

In section C, above, general conditions for the non-controversial exploitation of peaceful nuclear explosions were described. They show the general circumstances under which peaceful nuclear explosions are expected to occur and also indicate the kind and degree of involvement of parties in an international co-operation for such purposes. Deliberate disturbance by other parties of efforts to arrange for such non-controversial peaceful explosions seen well possible and would be a kind of misuse. The way to prevent such misuses is proper international procedure and control, designed to isolate effectively the peaceful nuclear explosive venture from other issues.

The author does not see manufacture of nuclear explosives for peaceful purposes by a non-nuclear-weapon State as a misuse of the option to exploit peaceful nuclear explosions under the presently proposed non-proliferation treaty. Such manufacture is not permitted to non-nuclear-weapon States under the treaty and would then be not a misuse but a basically different and less efficient way to maintain non-proliferation than the one attempted with the presently proposed non-proliferation treaty. Non-nuclear-weapon States producing nuclear explosives for peaceful purposes would not be parties to that treaty.
One may, of course, question whether such peaceful production can be verified to be just that and not a production for military purposes. International observers or inspectors would hardly be able to undertake such verification in a hostile and more or less closed environment. In a country friendly and open to observers and inspectors, such verification should be possible. The verification would then have to cover not only the development and production of explosives but the planning, organization, equipment and training of the armed forces. Such verification would not remove the destabilizing effect of such production on present non-proliferation efforts.

We now turn to the more technical misuses for the development and production of nuclear weapons under cover of treaties and other agreements. To be significant the opportunities for such misuse should permit their systematic preparation and exploitation.

The partial test ban treaty does not seem to provide any opportunities for systematic misuse of this kind. If that treaty were to be amended to permit peaceful explosions above ground for scientific purposes, misuse possibilities and control problems similar to those discussed below in the context of the complete test ban treaty would arise. The opportunities for misuse, however, would hardly be for systematic misuse. The special nature of the scientific purposes and their wide variability in kind make it difficult to generalize on the solutions of such problems.

Under the presently proposed non-proliferation treaty the main opportunity for misuse would be assistance by a non-nuclear-weapon State to a nuclear-weapon State in the development of nuclear explosives for peaceful purposes. The problem would be control against improper transfer of knowledge, despite precautions from one party (transfer of knowledge or even nuclear explosives between parties in collusion is, of course, impossible to guard against). Assistance of cooperation in this particular field should therefore be avoided. Then international expert observation of cooperation or assistance in the study or use of nuclear explosion effects for peaceful uses should be sufficient to remove possible apprehensions, provided that the cooperation and assistance is an open one. The prevention of the kind of misuse considered in this paragraph does not appear to present serious problems.

In the case of a complete test ban, on top of the proposed non-proliferation treaty, peaceful explosions offer several but limited opportunities for misuse for the maintenance or improvement of nuclear weaponry.
Peaceful explosions will offer the opportunity for limited training of some personnel designated to test explosions or to handle nuclear weapons in wartime. This advantage to nuclear-weapon States does not seem to be of great consequence. The peaceful explosions also offer opportunities for some elementary proof testing of weapon explosives in stock or delivered from the producer. If the peaceful explosions are made with explosives taken from a stock under international custody, the value of this proof-testing opportunity disappears almost completely. Both these opportunities for misuse would further be discounted against the value of contributing somewhat to the maintenance in credible shape of the nuclear deterrence balance by those who value that balance.

The main problem of possible misuse would be the opportunity for nuclear-weapon States to improve nuclear weapon design, using the peaceful explosions as test explosions. It would certainly not be advisable to permit, under a complete test ban, diagnostic measurements with peaceful explosions. Even if all peaceful explosions were closely observed by experts, to ensure (as is well possible) that no diagnostic measurements are made, the measurement of yield, radioactive debris and peaceful explosion effects necessary for the pursuit of the peaceful purpose itself would provide the nuclear-weapon State making the explosion with some limited opportunities to improve its nuclear weapons.

Two levels of limitation or control can be discussed. In one the nuclear-weapon States are permitted to supply explosives specially designed or selected by them for the purpose. The secrecy required by the nuclear-weapon State for its nuclear weapons and the essential identity of explosives for military and non-military purposes would make it impossible to control whether or not the nuclear-weapon State gains militarily, be it intentional or unintentional. Such possible misuses would be most probable in the case of explosions for the development of peaceful applications. In such applications there would be an effective obligation to use only well-tested and reliable explosive designs.

The second level of limitation or control would prescribe the use of explosives from a stock in international custody. In this case, of course, developmental improvements would be impossible; only some remote proof-testing gains would be obtainable and some training of personnel. The prohibition of all nuclear explosions constitutes a third and trivial level.
Control against improper diagnostic measurements is well possible for expert observers, if the supplier of the explosive waives some not completely essential explosives-area access regulations.

Control against the use of new explosives designs or evaluation of them as to their military importance, without using an international explosive stock, seems impossible because of foreseeable strict secrecy requirements by the supplier. Control of the keeping of explosives in a stock for peaceful purposes, under joint international and national custody, and control of the use of such explosives seems to be well possible. It would be a costly and somewhat complicated operation.

II. CONCLUSIONS

With the exception of above-ground nuclear explosions for peaceful scientific purposes, which are of only eventual importance and best considered ad hoc, peaceful nuclear explosions do not present problems of misuse for weapons purposes under the present partial test ban treaty. That treaty, however, is a serious problem for the development of peaceful nuclear excavation methods and an obstacle to their exploitation in small countries. The problem is essentially formal and could be removed by an amendment introducing health hazard limits for permissible over-border release of radioactivity.

Under the treaty for the prohibition of nuclear weapons in Latin America peaceful nuclear explosions are provided for on certain conditions. These do not impede the development and use of peaceful nuclear explosions methods in the case of co-operation with an outside supplier of nuclear explosion services. Under the control procedure of that treaty misuses by parties to that treaty could be avoided in cases of such co-operation.

Under the non-proliferation treaty peaceful uses of nuclear explosions are provided for. Nuclear-weapon States would supply explosion services to non-nuclear-weapon States. If assistance by non-nuclear-weapon States to nuclear-weapon States in the development of nuclear explosives for peaceful purposes is avoided, then international observational control of co-operation in the study and use of peaceful nuclear explosion effects should be able to prevent misuses or apprehensions about such misuses.

International co-operation in the development and use of nuclear explosions for peaceful purposes would, in any of these cases, be a complex undertaking, and many conditions, besides safeguards against misuse for weapons purposes, would have to be
satisfied to make such co-operation non-controversial. Isolation from other possibly controversial issues by proper international procedure would be helpful also as a safeguard against misuses of such co-operation for extraneous purposes.

Under a complete test ban treaty it would be very difficult or impossible to provide for effective development and use of nuclear explosions and to avoid, at the same time, all opportunities for intentional or unintentional and limited nuclear weapons testing. Some opportunities for limited misuse could be suppressed by safeguards, but that would be at the expense of crippling especially the further development of methods for peaceful uses of nuclear explosions, developments essential to efficient exploitation. The choice would be a matter of judgement on how to weigh the benefits of peaceful explosions against the drawbacks of some limited improvement of nuclear weapons.