# POSSIBILITIES FOR PEACEFUL NUCLEAR EXPLOSIVES

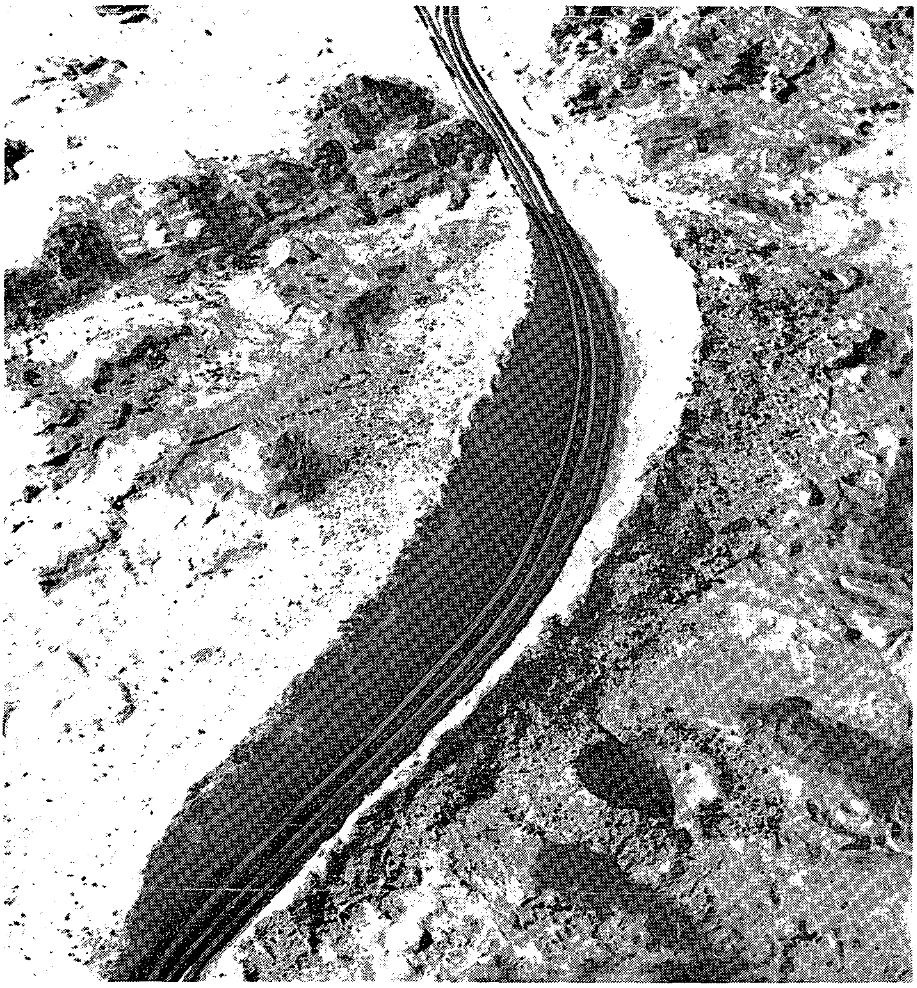
If peaceful uses of nuclear explosives become possible they could offer dramatic benefits. This explains the world-wide interest which has been aroused, and the investigations being made by the Agency in accordance with references made in the Non-Proliferation Treaty. In this article Bernard I. Spinrad, Director of the Division of Nuclear Power and Reactors, summarizes information at present available.

It is extremely rare to find a university textbook for the teaching of a very practical applied topic, before the subject has begun to be exploited; yet such a book "The Constructive Uses of Nuclear Explosives" (see references to literature) has been written on the subject of peaceful nuclear explosions. The topic has such dramatic possibilities that there has been a demand on the part of scholars and students to learn more about it. Additionally, it has been a subject of political and technical discussions with regard to the Test Ban Treaty and the Non-Proliferation Treaty, which have stimulated more general interest.

The idea that nuclear explosions could be used for civil works is, of course, not very new. The possibility was recognised by the witnesses to the first demonstration of a nuclear explosion at Alamagordo. The subsequent underwater test at Bikini Atoll in 1946 confirmed that an extremely strong shock wave could be propagated in condensed matter by a nuclear explosion, by sinking a fleet of obsolete and surplus naval vessels. The first nuclear explosion in the USSR was reported in their press as an experiment in civil explosive engineering. Finally, the dramatic Eniwetok test of a thermonuclear explosion demonstrated that a large explosion could, in fact, demolish a Pacific Atoll and, indeed, leave a cavity where an island had been.

Starting in 1956, the USA in particular began to study seriously the possibilities for peaceful application of nuclear explosions. Two items of progress were partly responsible for this programmatic action: first, the theory of explosion effects had been very much advanced by the introduction of large-scale computers and their ability to obtain solutions to very complex theoretical models; second, advances in the design of thermonuclear explosives made it possible to conceive of much "cleaner" explosions, with only a small fission component and consequently fewer fission products, and thus decreased the potential radiological contamination from nuclear explosions.

Although one of the earlier suggestions for peaceful nuclear applications was for spacecraft propulsion, subsequently all proposed applications have been for underground explosions. This is not surprising; the same is true for conventional explosives as well.



Concept of a railway and highway pass through mountains cut by nuclear explosives. It was made following a USA technical feasibility study. Photo: Lawrence Radiation Laboratory

The first formal programme for peaceful applications was announced by the USA in 1957, under the title "Plowshare", and the first underground test, RAINIER (which was not, in fact, a Plowshare operation) was performed in the same year. From 1958 to 1961, during the informal nuclear test moratorium, the Plowshare experimental programme consisted of chemical high explosive experiments, which led to a much improved understanding of underground explosive phenomena. Explosives engineering experience in other countries, notably the USSR, also added to this understanding.

In 1961 and subsequently, the USA again performed underground nuclear experiments, including the first nuclear Plowshare test, project GNOME. Since then, experience has been accumulated and codified, and it is possible to consider international applications of a commercial nature.

## WHAT HAPPENS UNDERGROUND

In order to understand better the possible applications which have been proposed, it is useful to review and discuss what happens in an underground nuclear explosion.

In the first phase of firing (which lasts only for millionths of a second) almost all the energy of the nuclear explosion is released. A fireball, in which internal temperatures of millions of degrees and internal pressures of millions of atmospheres exist, is formed. The surrounding rock is vapourised by absorption of energy from radiant heat and other radiations, with a boundary of molten rock. Thus, a cavity several metres across may be formed.

Within a few thousandths of a second, the pressure wave within the cavity strikes the cavity wall. The cavity is further expanded by plastic deformation of the surrounding rock, and the fluid layer increases in thickness through melting following some absorption of the mechanical energy. Most of the pressure energy is converted into a shock wave which travels outward from the explosion. Until its energy has been dissipated, this shock wave interacts with the surrounding rock by crushing and fracturing it. This behaviour, as is the case with the other shock phenomena described below, is not qualitatively different from the effects of chemical high explosive shots; the differences are in scale - the much larger energy in the nuclear shock and the smaller relative size of the central cavity.

Within a period of seconds, the molten rock liner of the cavity starts to flow and aggregates at the bottom. This molten zone contains most of the radioactivity of the nuclear explosion. Ultimately it will freeze, and it is finally found as a bowl-shaped mass, considerably cracked as a result of thermal stresses and of mechanical blows from other rock falling on to it.

In a contained explosion, the fractured rock zone above the cavity is not solid enough to bridge over the hole. Some of the broken rock falls in from above, filling the cavity with looser rock. As this happens, more rock continues to fall from above, until the point is reached at which this relatively loosely packed region begins again to support the rock above it, and the less badly shattered rock acts as a bridge. The result is a cylinder filled to low density with broken rock, called a "chimney". If the explosion is deep underground, no surface effect can be seen. It is possible, however, for chimney formation to result in some slumping of the earth at ground level; if the explosion were too close to the surface, the chimney could extend to the surface, and cracks in the ground would be found.

For cratering activities, the explosive is detonated at a depth such that the shock wave will reach the surface and be partially reflected and refracted at the ground-air interface. The returning wave reaches the cavity while it is still growing, and causes it to expand preferentially upward and outward. As a result, a large dome of earth and rock rises above ground level. Ultimately the dome is breached, through a combination of effects: decreased cavity pressure from its expansion, release of cavity gas through fissures in the dome, and gravity. Then the dome falls back; however, by this time a large mass of material has been pushed outward. The result is a crater, with a rim of crushed, loose rock, and a floor of broken rock lying above the location of the detonation. The molten and resolidified rock zone still exists, but is buried under the crater floor.

As indicated, the largest part of the radioactivity in the nuclear explosion is retained in the molten zone. Most of the rest is retained on the surfaces of the crushed and fractured rocks, which are good natural sieves for particulate matter and absorbers for vapour. In a cratering explosion, however, some radioactivity will escape to the atmosphere. The amount of fission products is estimated as a very small fraction of the potential quantity: in a 25 kiloton explosion, which is largely thermonuclear, fission product release is limited to the products of a 20 ton fission explosion – about 8 grammes of product. Neutron activation is minimised by surrounding the explosive with a non-activating, neutron absorbing shield. Some tritium from the thermonuclear explosion is released.

## COMPARISONS WITH TNT

As has been mentioned, the nuclear explosion differs in equivalent size from chemical high explosives by several orders of magnitude. A 25 kiloton nuclear explosive (TNT equivalent – 25 000 tons) may be emplaced in a cylindrical bore hole less than a metre in diameter; even a 1 megaton explosive charge (TNT equivalent - 1 000 000 tons) would not take up more space than that. On the other hand, 25 000 tons of TNT would require a spherical cavity, 30 metres in diameter. Even if that much TNT could be assembled in one place, its emplacement costs would be enormous.

Nuclear explosives are also relatively inexpensive. The USAEC has projected a charge of $350 000 for a 10 kiloton and $600 000 for a 2 megaton explosive. Equivalent TNT costs are, respectively, $4 000 000 and $800 000 000. Thus, even for "small" shots, potential economies are considerable, while for large ones, chemical explosives simply are not economically feasible.

## THE USES

Nuclear explosions have been proposed for spaceship propulsion as previously mentioned, for scientific experiments, for isotope production and for power production. This article, however, is concerned with subjects within the general fields of mining and civil engineering. These are: the creation of underground storage areas; the extraction of minerals and petrochemicals; and the construction of large civil works including geographical projects.

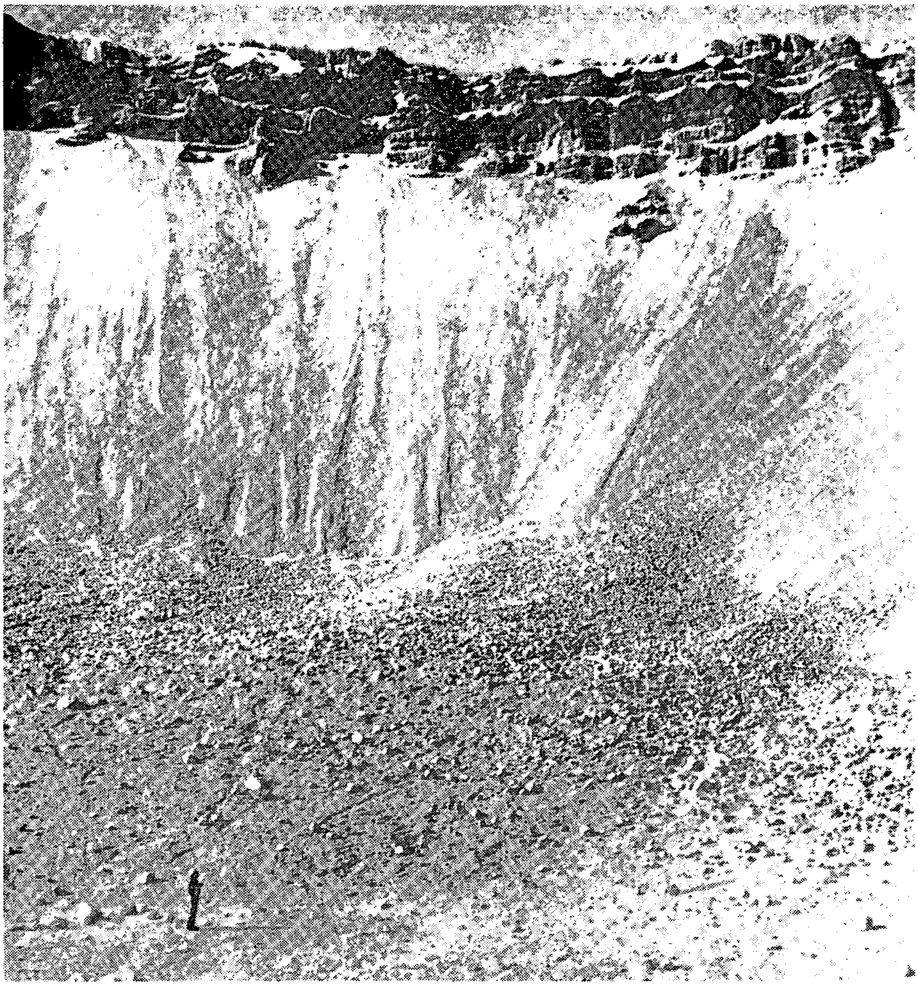
The creation of underground storage areas is one possibility. The chimney and the crushed rock zone around the nuclear detonation have a considerable void volume. It is estimated that a 100 kiloton explosion, for example, would result in a reservoir capacity of over 350 000 cubic metres. If the explosion were at at the proper depth, and the strata affected were surrounded by impermeable rock, such a reservoir could be used for storage of such fluids as water, oil and natural gas. Problem areas which exist for this application are: degree of contamination of reservoir fluid with radioactivity; integrity of surrounding rock under the additional load of stored fluid pressure; verification and determination of reservoir capacity as a function of explosive yield and geological considerations; and, of course, cost.

The extraction of minerals and petrochemicals is receiving the most attention now. Project GASBUGGY has already been performed and Project RULISON is scheduled for September this year; these are both experiments in stimulating production of natural gas. The concept is to increase the permeability of rock strata containing the gas by means of the large scale cracking of the rock following a deep underground explosion. "GASBUGGY" results have been partially released: gas flow has been stimulated as expected, and contamination is low except for tritium, which, however, is also less than predicted. The main results of the experiment will, however, take some time to evaluate: the questions are whether the gas production will remain high for an economically useful period, and the radioactivity will fall to an acceptably low level as expected.

A related concept has been the production of oil from shale. Again, the hope is to render permeable a considerable volume of oil-bearing rock, so that retorting on the site could be feasible. An experimental programme is necessary to evaluate the degree of permeability subsequent to the explosion and to provide a field laboratory to test the retorting and extraction of the petroleum. Although the concept is still considered speculative, the payoff for successful development would be enormous: it is estimated that over 99% of the world's petroleum is to be found in oil shales.

Still another concept of this sort involves the preparation of underground ore bodies for leaching, a very attractive alternative to deep mining for such metals as copper and uranium. An experiment in a copper body has been proposed. Provided that the desirable permeability is achieved, this is a rather promising application, since the required chemical processing of the ore would make it easier to purge many potential radioactive contaminants.

Also worth consideration as possibilities are more conventional mining applications. Large explosions could conceivably reduce the costs of strip mining of hard ore bodies lying not too far from the surface by eliminating a need for chemical high explosives. The possibility of draw mining material,



Inside a crater formed in Nevada by the Sedan experiment, USA, to obtain information on the use of nuclear explosives for earth-moving projects. A 100-kiloton (equivalent to 100 000 tons of TNT) thermonuclear device was used, forming a crater 352 metres wide and 97 metres deep with edges from 6 - 32 metres high. When this picture was taken seven months later radiation levels were so low that no protective clothing was needed. Photo: Lawrence Radiation Laboratory

at least from the chimney, was tested in 1962. A mine shaft was driven to within 30 metres of the detonation point of a 5 kT nuclear shot and 2 700 tons of broken rock were removed without radiation hazard.

In the construction of large civil works, one can traverse a scale ranging from relatively straightforward quarrying and ground breaking all the way to major geographical alterations, such as the bulding of harbours, canals, and the division of waterways. At the lower end, it is clearly possible to fracture a considerable amount of rock rather inexpensively in order to make its removal easier, as might be desirable for railroad and highway cuts in mountainous areas. In such construction also, but particularly in building dams in isolated areas, nuclear explosions can be used to permit quarrying the broken rock, as for the production of concrete aggregate. It takes only a little imagination to conceive a situation in dam construction where a cratering shot is employed both to move a considerable quantity of rock to the point where a stream is to be blocked, and to provide broken rock for concrete aggregate.

Major canals can be very expensive to construct by conventional means. For example, the United States is interested in building a new sea-level canal across the Central American isthmus. A number of routes have been surveyed and costs of conventional construction estimated; these costs inevitably run to several billion dollars. Meanwhile, nuclear explosion technology has advanced, and it is possible to predict the ability of a row of charges to create ditches. Thus, Project BUGGY-I, the first nuclear ditching experiment, consisted of the simultaneous detonation of five nuclear charges, each of 1 kT, at a depth of 40 metres and at appropriate spacing. The experiment resulted in a ditch 20 metres deep, 75 metres wide and 260 metres long in hard rock, essentially as predicted.

It is therefore possible that this technique could be used in canal building with a considerable savings in cost, on the successful outcome of experiments which are still only in the conceptual stage.

Should the nuclear canal-building technique be feasible, there are a number of other locations where it may be attractive. These include the Malay Peninsula, and several locations in North Africa which would create bays of the Mediterranean Sea in depressions of the Sahara. (An interesting feature of this latter proposal is that it may be possible to use the canals from the Mediterranean for power production rather than for creation of bays; Mediterranean water would be admitted through a dam, and after giving up its mechanical energy would evaporate, permitting almost indefinite operation of the system.) In all continents, there are significant river diversion possibilities, which might benefit both from nuclear dam building and nuclear ditching.

A final type of project is the creation of harbours. The cratering type of nuclear explosion, in shots of larger yield can make very impressive depressions on the land surface or at the water's edge. For example, Project SEDAN, fired in 1962, was a large (100 kT) nuclear explosion fired at a depth of 190 metres. Its purpose was to test and evaluate such an explosion, which was calculated to yield a maximum-size crater. The crater, somewhat larger than expected, was 100 metres deep and 350 metres in diameter. Radiation was not a severe problem, the bulk of the radiation being trapped in the region of the central cavity, about 90 metres below the crater floor. About seven and a half million cubic yards of earth and rock were displaced.

With shots of this magnitude, "instant" harbours could be created in locations where the rock floor of the sea is not at a great enough depth to permit docking of large vessels. Projects of this sort have been seriously proposed for locations in Alaska and Australia; these have been abandoned for the time being, but it is very likely that projects of this type will be activated in many places throughout the world.

## WHERE WE STAND

Although our knowledge of explosions, and particularly of nuclear explosions, has improved greatly in recent years, there are nevertheless many problems which still exist in evaluating any given project. The effects of blasts are different in different rocks, and are affected by errors in the characterisation of physical properties of the rock, and by the heterogeneity of rock masses. The scaling laws for blast effect have been verified in their general form but second order effects are not precisely known. Finally, the predictability of the explosive yield of the devices used is not known well enough, at least outside of nuclear weapon states.

The features of the radioactivity questions are also known qualitatively rather than quantitatively. It is known that the greatest part of the radioactivity is trapped and held in the layer of molten rock which forms around the fireball, and that fractured rock with small fissures is a rather good absorbing medium for radioactive products. What is not known is the exact fraction of radioactivity which will be released for a given shot, particularly near the surface. Neither is the release rate of the fractured rock for its absorbed radioactivity fully known. With regard to initial releases it is expected that the nuclear powers will be able to furnish quantitative data from tests so far conducted for scientific scrutiny. As far as the slow release of radioactivity from an underground explosion is concerned, the scientific investigations of Project "GASBUGGY" should be very revealing but other tests in other materials and under other circumstances should be carried out since it is both unscientific and dangerous to rely upon one or a few sets of measurements. Finally it will be necessary to examine the data bearing upon continued release, over long periods of time, of radioactive materials trapped in harbour and canal digging projects. It is expected that such releases will not be consequential but all possible factors, both chemical/ hydrological and biological/ecological must be examined.

It is very necessary that research investigations in seismology, geology, ecology and hydrology should accompany peaceful nuclear explosion projects. These subjects are required to predict project effects, and support to basic knowledge in these related disciplines is needed to ensure against unpleasant surprises.

To sum up: our current state of knowledge is sufficient so that we may qualitatively evaluate the costs and benefits of such PNE applications as canal and harbour building, and creation of underground reservoirs. The quantitative evaluations both of the technology and of side effects to be expected require more research. Selected projects which are desirable even under the most conservative assumptions as to risks can be carried out. However, there is a large class of projects which could not be definitively proposed for execution on the basis of current information.

With regard to explosion projects involving mineral recovery, there is an additional uncertainty in that the peaceful nuclear explosion itself is only a preparatory condition for the actual application. In extracting natural gas and petroleum, the degree of stimulation over a period of time is still to be determined and questions of product contamination must still be examined. With regard to oil shale, the recovery process is still to be demonstrated; and so on.

## WHEN?

It is generally agreed that still more experimenting is needed before countries possessing nuclear explosives will be able to use them for actual projects; the experiments being themselves useful pilot projects only. At the same time, it is necessary to have considerably more information exchanged and released, so that the benefits of peaceful nuclear explosions can be evaluated by all possible users. The International Atomic Energy Agency is taking particular interest in this information exchange, as one of the ways of fulfilling its statutory mission of furthering all peaceful uses of nuclear energy. It is believed that it will take at least five years to develop and exchange all the information which will be necessary to undertake even the most straightforward projects, and that there will only have been a few such completed by 1980. Thereafter, however, the use of nuclear explosions is likely rapidly to become a standard - although never routine - technique in civil engineering and mining.

## SOME LITERATURE ON PEACEFUL NUCLEAR EXPLOSIVES

"The Constructive Uses of Nuclear Explosives", by E. Teller, W.K. Talley, G.H., Higgins and G.W. Johnson, McGraw-Hill, New York (1968). This is a text book of 315 pages, prepared for a lecture course to college seniors and graduate students in science and engineering. It contains, however, considerable descriptive material on the phenomenology and applications of nuclear explosions.

"Nuclear News", Vol.11, No.3, pp.23-44 (March 1968). A good summary, at the technical level of news for scientists, of the main features of U.S. thinking on PNE.

"Formation of an Excavation by a 1009 Ton Throw-Out Blast", by A.N. Deshkov. Report UCRL-Trans-10138, University of California, Livermore, California. Translated from Russian: Transp. Stroit., 10: No.11, pp.10-12 (1960). This report is of interest as an illustration of the use of conventional HE, in a quantity to give a yield in the range of nuclear explosions, for civil works. Such technology is highly developed in USSR.

"Engineering with Nuclear Explosives"; Proceedings of the Third Plowshare Symposium, April 21-23, 1964; Report TID-7695. Clearing House for Federal Scientific and Technical Information, National Bureau of Standards, U.S. Department of Commerce, Springfield, Virginia. About 380 pages of text, consisting of thirty brief scientific reports on virtually every aspect of PNE. The treatment of topics is irregular, ranging from detailed scientific discussion to presentation of estimates or results.

"Peaceful Uses of Nuclear Explosive – An Evaluation for Australian Purposes, of Proposed Civil Engineering and Mining Applications" by A.R.W. Wilson, E.B. Pender and E.K. Carter. Report AAEC(SP)/R1, Australian Atomic Eenrgy Commission, Sydney (1964). A general report of over 200 pages, summarizing applications and indicating thereby the information which could be made available to a possible beneficiary country at that date.

"Commercial Plowshare Services"; Hearings before the Subcommittee on Legislation of the Joint Committee on Atomic Energy, Congress of the United States; Ninetieth Congress (July 19, 1968). U.S. Government Printing Office, Washington. This is a document of over 400 pages in length, the largest part of which consists of technical papers covering the feasibility of experimental nuclear explosions for a variety of purposes. Also included are other technical papers on explosion prediction, general information, and certain Congressional testimony.

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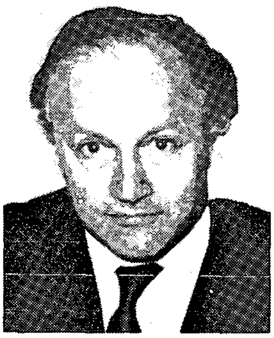
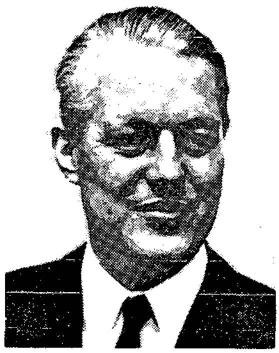

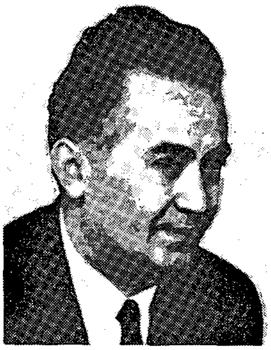
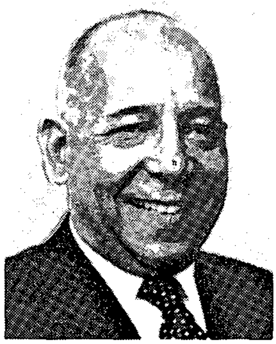

Recent visitors to the Agency have included (left to right) Lord Chalfont, UK Under-Secretary of State charged with special responsibility for foreign affairs, paying a courtesy visit; Dr. Gerhard Stoltenberg, Minister for Scientific Research of the Federal Republic of Germany; Mr. Lennart Petri, Ambassador to Austria and new Resident Representative of Sweden to the IAEA; Mr. Dhimiter Tona, Ambassador to Austria and new Resident Representative of Albania to the Agency; and Mr. Gabriel d'Arboussier, Ambassador to Austria and new Resident Representative of Senegal to the Agency. The last three were presenting their credentials.