Apppendix II. Peaceful Nuclear Explosions

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Appendix II

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Table of Contents

APPENDIX II

Peaceful Nuclear Explosions

The potential of nuclear explosions for both destructive and beneficial uses has posed a persistent arms-control dilemma: What measures can be taken to deny nuclear weapons to a nation without also denying it the possible benefits of peaceful nuclear explosions? A happy solution seemed to have been found in the Non Proliferation Treaty (NPT) , which forbids non-nuclear weapons states to develop nuclear devices of any type, but which simultaneously promises these nations any benefits from peaceful nuclear explosions (PNE's) on a non-discriminatory, low-as-possible cost basis. Hence, the non-weapons states would never have to develop the technology to produce nuclear explosives, which is essentially identical to the technology for producing nuclear weapons.

Since the signing of the NPT, however, the hopes for benefits from PNE's have continued to fade while the concern over their abuse has continued to intensify. India underscored this concern in 1974 by detonating a nuclear blast which she claimed was for peaceful purposes. Other nations have noticed that India suffered very few repercussions for her actions. Nations who are parties to the NPT are of course constrained from following India's example. Nevertheless, they could potentially feel disappointed that none of the promised wonders of PNE's have been made theirs, and resentment has been expressed over the discriminatory approach of the NPT. These factors could put an additional strain on nations' willingness to abide by the NPT.

The present dilemma might then be rephrased: What measures can be taken to prevent PNE's from being used as either an excuse or an incentive for weapons development? Suggested solutions range from a complete ban on PNE's to an international regime that would provide them to all nations. The selection of any solution should be made only after a study of what hopes the various nations have placed on PNE's and whether these aspirations are well founded.

Historical Background

The promotion of the peaceful nuclear applications of nuclear power began in the 1950's, with President Eisenhower's "Atoms for peace" speech in 1953 perhaps symbolizing the start of the era. Scientists at the Lawrence Livermore Laboratory (LLL) helped initiate the government sponsored Plowshare Program in 1957 to research commercial and civil engineering projects that could be undertaken with nuclear explosions. Some critics now feel these scientists may have been too committed to their work in nuclear explosives to take a sufficiently dispassionate view of PNE's.[1] No matter what the motive, however, there clearly were legitimate reasons for exploring the idea that nuclear bombs could create as well as destroy.

The optimism of the early researchers was reflected in their presentations at various international conferences from the late '50's to the early '70's. Peaceful nuclear explosions were first mentioned at the second of four Conferences on the Peaceful Uses of Atomic Energy (1955, 1958, 1964, 1971) sponsored jointly by the U.N. and the IAEA, and were further described in the last two of these conferences. The U.S. conducted four symposia (1957, 1959, 1964, 1970) as part of the Plowshare Program. At all these meetings the various nations in attendance were stimulated to dream of grandiose nuclear engineering projects that might develop their domestic resources at a low cost.

These high expectations for PNE's had to be recognized when the NPT was drafted. The Treaty allowed non-nuclear weapons states to receive the benefits of PNE's even though they would not be permitted to develop their own nuclear explosions. Any nation that was truly serious about its plans to use PNE's should have welcomed this provision of the NPT, for most non-weapons states lack the sophisticated nuclear technology to develop an explosive with the stringent requirements of one intended for domestic applications. Such devices must be manageable small, yield minimal amounts of radiation and bear a low price tag.

Provisions of Article V

The specific provisions for peaceful applications of nuclear explosions are contained in Article V of the NPT, which reads as follows:

> "Each Party to the Treaty undertakes to take appropriate measures to ensure that, in accordance with this Treaty, under appropriate international observation and through appropriate international procedures, potential benefits from any peaceful applications of nuclear explosions will be made available to non-nuclear-weapons States Party to the Treaty on a nondiscriminatory basis and that the charge to such Parties for the explosives used will be as low as possible and exclude any charge for research and development. Non-nuclear-weapons States Party to the Treaty shall be able to obtain such benefits, pursuant to a special international body with adequate representation of non-nuclear-weapons States. Negotiations on this subject shall commence as soon as possible after the Treaty enters into force. Non-nuclear-weapon States Party to the Treaty so desiring may also obtain such benefits pursuant to bilateral agreements."

The wording of Article V of the NPT has created some problems with subsequent interpretation. From the start, the U.S. was concerned over what it viewed as an open-ended commitment implied in the Article.[2] To what extent does it obligate the nuclear powers to provide the peaceful benefits of nuclear explosions? Should they be actively developing and promoting the applications of PNE's or more passively providing the PNE's only if their benefits are unambiguously determined? It is also unclear whether a nuclear power must provide PNE's to a nation when they are either hazardous, uneconomic or in some way inappropriate to the job proposed.

A second uncertainty about Article V concerns the exact nature of the "special international agreements" and the identity of the "appropriate international body". Some may have envisioned that an agency would be promptly established to provide nuclear explosives and services for any peaceful domestic projects. The actual implementation of Article V, however, seems to be evolving slowly. perhaps because of the continued uncertainty over the relative merits and demerits of PNE's.

The International Atomic Energy Agency (IAEA) was perhaps the natural candidate to be the "appropriate international body" mentioned in the NPT. In 1971, the U.N. Secretariat asked the IAEA to "exercise the functions of an international service for nuclear explosions for peaceful purposes". The statement did not clearly define what those functions would be and suggested that the IAEA study the ways and means to carry out this task.

So far the IAEA seems to have defined its role as a fairly limited one. It has developed procedures for the international observation of peaceful nuclear explosions, as called for in Article V. It has further sought to gather and disseminate technical information about the nonmilitary application of nuclear devices. It has done so through the sponsorship of a series of international technical meetings (1970, 1971, 1972, 1975, 1976), through participation in the International Nuclear Information System and most recently through the establishment of an office to handle the information exchange and service requests.

In 1974 the IAEA developed procedures for responding to requests for PNE-related services. The services envisioned to date are assistance with preliminary, pre-feasibility and feasibility studies. In fact, a team from

IAEA, at the request of Egypt in 1976, did conduct a preliminary review of the possible use of nuclear explosions in connection with the construction of a canal from the Mediterranean Sea to the Qatarra Depression. No procedures have been defined for responding to requests for services beyond the feasibility-study stage , Such longer-range plans will be on the agenda of the Ad Hoc Advisory Group on Nuclear Explosions for Peaceful Purposes, created by IAEA in 1975. One of the tasks of this group is to advise the Board of Governors on the question of an international service for PNE’s as well as on the structure and content of the “international agreements” mentioned in Article V“.

In general, the IAEA seems to see its role as that of an intermediary - facilitating exchange of information and providing a liaison between those nations requesting PNE services and those nations willing to provide consultation or actual explosive devices.

Effect of PNE's on Test Ban Treaties

PNE's have complicated negotiations for test ban treaties. The only test bans that have been negotiated between the U.S. and the U.S.S.R. are the 1974 Threshold Test Ban (TTB) Treaty and its associated 1976 Treaty on Underground Explosions for Peaceful Purposes (the so-called PNE Treaty, which is till not ratified but which was a prerequisite for implementation of the TTBT). Both have been criticized for blocking rather than paving the way toward a comprehensive test ban.

The major objection to the Threshold Test Ban Treaty is that is poses very little hindrance to weapons tests: the upper limit of 150 kton is 10 times the size of the bomb dropped on Hiroshima. The PNE Treaty places the same limit on the size of nuclear explosions for peaceful applications as the TTB does on nuclear weapons tests. This provision was necessary because both sides admitted during the negotiations that no one can verify that PNE's are not being used for weapons development--even with the on-site observations that constitute a unique feature of the PNE Treaty.

The unfortunate aspect of the PNE Treaty is that it is a separate treaty. It was negotiated separately largely in deference to the Soviets, who claim an active interest in a PNE program. (Ironically enough, it was the Soviets who, thirteen years earlier, had opposed U.S. efforts to exclude PNE's from the Limited Test Ban Treaty.) The existence of a PNE Treaty legitimatizes a separate status for such peaceful nuclear devices and invites other nations such as Brazil to use the same excuse for nuclear weapons development as India did. Furthermore, the PNE Treaty will complicate any attempts to reduce the upper limit on tests set in the TTB. Because the treaties have recognized the indistinguishability of weapons and PNE tests, no reduction in weapons tests is likely as long as interest remains in larger PNE tests.

In view of these complications in arms control introduced by the concept of beneficial applications of nuclear devices, it is necessary to examine whether any of the potential benefits are worth this price.

U.S. Program on PNE’s

In the nearly twenty years since the start of the Plowshare Program, many beneficial applications of nuclear explosions have been extensively studied in the U.S. Despite the initial enthusiasm over the Program, most of the recent reports manifest decreased optimism. The U.S. budget for PNE’s reflects the same trend: After having spent $160 million on PNE experiments, the U.S. currently has alloted about $1 million per year for PNE’s. Of that, $300,000 is earmarked for research on using PNE’s to create storage cavities for radioactive wastes. The remaining funds are for the purposes of fulfilling the obligations of the NPT.

The Plowshare Program investigated both of the two general categories of nuclear explosions for peaceful purposes: excavation projects and contained explosions. (See Table I for a chronology of the Plowshare Program.) One of the more prominent excavation projects--the construction by nuclear means of a sea level canal to supplement the Panama Canal--was studied by the Atlantic–Pacific Interoceanic Canal Study Commission, appointed in 1965. In its final report in 1970, the Commission gave the concept a rather negative assessment. A major finding was that the technology of nuclear excavation was not yet sufficiently advanced. In addition, the necessity of locating the canal route far from population centers to avoid seismic and radiation damage raised costs above those estimated for construction with conventional explosions.

Although there are some locations where the economics are more favorable for nuclear excavation projects, the other factors that hindered the isthmian canal project are still present. The technology knowledge does not yet allow precise predictions of crater depth and width or of crater lip stability. Furthermore, the trough created by a given nuclear explosion must be accepted as is, for the area is too radioactively hot to permit immediate modifications, as is possible with conventional explosions. Even if these technical problems could be surmounted, the health and environmental problems still remain Seismic effects. air blast and radiation from a nuclear detonation are severe enough to necessitate evacuation of the local population, often for extended periods of time. Research on bomb design has resulted in "cleaner" bombs--ones that shield the neutrons and that have a *large* thermonuclear component to minimize the production of biologically significant fission products. The research has resulted in order-of-magnitude decreases in radiation, but some radioactivity is released.

The radiation releases constitute a political as well as a health constraint on excavation applications. The Limited Test Ban Treaty of *1963* forbids any nuclear explosion for any purpose that would spread radioactive debris beyond the border of the nation conducting the explosion. Wishing to abide by this treaty and discouraged by the many negative factors of nuclear excavation projects, the U.S. halted this phase of PNE research in *1969*.

<u>Contained Applications: General Factors</u>

Although hopes for nuclear excavations are dead in the U.S. , interest in contained nuclear explosions is still alive. One reason is that nuclear explosions have a far greater energy density than conventional chemical explosions. Thus, the size and weight of a nuclear explosive can be about 1/10,000 of the size or weight of a chemical explosive that would accomplish the same job. This logistic advantage also leads to an economic advantage:

The cost of a nuclear device has been estimated to be about 1/10 that of a comparable chemical device, for those with a yield of 10 kt or higher (these estimates are somewhat speculative). In addition, the cost of the nuclear explosion does not increase much as the yield goes up. A 1,000 kt device costs little more than a 100 kt device. This fact tends to favor applications with large yields.[5]

The exact pricetag on a nuclear explosive is technically a military secret. Current estimates are that it would be somewhere between $400,000 and $1,000,000.[6] The costs associated with its use - such as device emplacement, monitoring, evacuation - roughly double the cost of the device.[7] None of these costs reflects the research and development expense, most of which has been covered by the weapons program[8] and the AEC Plowshare Program.

Some additional interest in PNE's has been stimulated recently by the energy crisis. The emphasis on decreasing our reliance on foreign sources of petroleum products and the increased cost of such energy sources has made it worthwhile to develop domestic reserves that were previously ignored. It is hoped that nuclear explosions might stimulate production from tight gas formations, assist in retorting oil shale in situ or perhaps create underground storage caverns for oil, gas or liquified natural gas (LNG).

A detailed evaluation of these and other possible applications of nuclear explosions in the U.S. was completed by the Gulf Universities Research Consortium (GURC) in 1975.[9] Their task, commissioned by the Arms Control and Disarmament Agency, was explicitly to project the use of PNE technology up to the year 1990. They found that the technical uncertainties surrounding most of the proposed projects were so large as to preclude any economic analysis except a range of cost estimates. Nevertheless, even with the most optimistic assumptions, the GURC study concluded that any PNE application before 1990 was highly unlikely. Their report underscores some general factors that all PNE applications have in common:

"1. Technical uncertainties. The impact of a nuclear explosion in particular circumstances can not yet be accurately predicted and the results vary with such factors as the type of rock, depth and size of explosive. Technical uncertainties also surround the non-nuclear aspects of most of the proposed applications. Finally, the quantity, quality and properties of the resource to be exploited are rarely known with great certainty.

2. Economic uncertainties. Until the technical questions are fully answered, firm cost estimates of various applications are difficult to make. The GURC report could make economic predictions only by assuming success for each of the various development stages. On this hypothetical basis the report found that some applications of nuclear explosives might be commercially competitive.

3. Regulatory Questions. A major factor in preventing or at least retarding the application of PNE's is the public opposition to it. Already two restrictions loom as handwriting on the wall, especially against the background of resistance that has been faced by the nuclear power industry. One of these restrictions is a state constitutional amendment that was passed in Colorado in 1974 to ban the conduct of any nuclear tests unless approved by a statewide referendum. (Colorado was the site of two contained

nuclear experiments and possesses considerable quantities of gas and oil shale that are being proposed for development by PNE's.) Separately, Congress in 1974 passed a provision in the ERDA budget that prohibits funds from being used for PNE tests. If further public resistance developed to any attempt to accelerate the PNE program, it would produce considerable delays and would raise the costs.

4. Supply of PNE's. Nuclear explosives are necessarily a government monopoly and would have to be supplied to the industry by the government if an actual PNE program developed. Some of the proposed applications envision several hundred PNE's per year, and the industry would have to be assured of a reliable supply. The government would presumably have to establish a production line to provide the required number at a reasonable cost. Close coordination with the intended user would have to be maintained, especially in the early phases of production start-up. Another problem could conceivably be the competition of the PNE program with the Defense Department and the nuclear power industry for a supply of nuclear fuels.[10]

5* Environmental Effects. Seismic damage is a limiting factor for most contained PNE applications. The damage to buildings and necessity of evacuation restricts the use of such techniques to areas of low population density. Repeated detonations in the same area might also cause appreciable ground rise and additional damage to structures. While the radiation from a contained explosion is not released in large quantities into the air, as with an excavation, small amounts of radioactivity can still find their way out: Some might be vented to the air, some can seep into the ground water and some might be mixed with the product being mined or extracted. Finally, the ever present though small risk of accident becomes multiplied by the large number of explosions required for most of the PNE uses.

6. Success of Competing Technology. Almost every task proposed for PNE's can be accomplished by other techniques. Often the alternative is either more costly or in an early stage of development, but research on less controversial techniques may advance more quickly.

Increased Production of Gas Resources

A look at the most frequently discussed PNE proposals gives insight into how all these general factors operate in particular circumstances. One application that has received considerable attention is the stimulation of tight gas formations. These formations are regions where the permeability is too low to allow the gas to flow into wells at sufficiently fast rates. If the permeability could be increased by using a nuclear explosion to fracture the rock, the rate of recovery might be appreciably improved. A series of three such explosions were conducted in the Rocky Mountain states. The first two - Gasbuggy (a 29 kt explosion in 1967) and Rulison (43 kt in 1969) - produced some positive increases in gas flow. The third one - Rio Blanco (three devices of 30 kt each in 1973) - was a disappointment and has been one cause of general disillusionment with PNE's. The objective of the Rio Blanco test was to connect three lenticular regions by exploding three blasts simultaneously at different depths. Tests indicate the chambers did not connect as planned and gas yield was lower than expected. A fourth planned test of gas stimulation has not been scheduled.

The Rio Blanco test failure illustrates the lack of knowledge of critical parameters. The permeability of the rock and the amount of gas may not have been well enough known. The effect of the blast on the rock evidently were not predicted correctly. The unknown effects include the height of the chimney (perhaps underestimated in this case), the fracture patterns and the rate of healing of the fractures, which would slow production over a period of time.

Even if the technology did succeed, this application of PNE's would face some environmental problems. The gas produced might have some radio-active contamination (albeit at a low level) that might affect its marketability. This application also calls for a larger annual number of PNE's (as many as 450 per year)[11] than most other proposals.

The major competitor to PNE's for gas stimulation is the technique of massive hydraulic fracturing (MHF). A mixture of sand and water at high pressure is pumped into the rock to fracture it. The sand prevents any healing of the fractures. Estimates are that PNE's are cheaper than MHF for the stimulation of gas reserves but by a margin that is less than the range of uncertainty in the estimates.[12]

Stimulation of Oil Wells

The use of nuclear explosions to stimulate production from oil reservoirs is less promising than gas stimulation. There is virtually no interest in this application in the U.S. Many fear it might result in long-term damage to the reservoir, and several alternatives for enhanced oil recovery are available.[13]

Extraction of Oil from Shale

A third potential use for nuclear explosions is to assist in the recovery of oil from the shales in the Rocky Mountain Basin. The amount of oil that might be ultimately recoverable exceeds the cumulative domestic production of crude oil up to 1974.[14] The recovery of this large resource poses equally large problems. The petroleum is present in the shale in the form of an organic compound called kerogen which must be heated to
8 800 F before it turns into a fluid that can be extracted.

The best known method for extracting the shale oil is open-pit mining and above ground retorting. A perhaps preferable variation is to replace the open-pit mines with underground mines. Still both methods have severe problems. The above ground retorting requires large amounts of water whereas the surrounding areas are typically quite arid.[15] It also results in an accumulation of depleted shale above ground which presents a disposal problem. Finally, it requires relatively high quality shale.

To avoid these problems of above ground retorting, several in-situ techniques are being studied. In the Garrett process, an underground cavity is mined. A conventional explosion is detonated in this cavity to create a rubble-filled chimney. A combustion front is then started at the top of the chimney and continues to advance downward as air is fed in. The liquid product, similar to crude oil, forms in a pool at the bottom and is pumped to the surface. Gaseous products are also collected. The low Btu liquid usually requires further processing at the surface.

An alternative to the Garrett process is to use a nuclear device to create the rubble-filled chimney. This application may require explosives ranging from 30 to 130 kt for depths of detonation from 900 feet to 1900 feet.[fi] Perhaps 100 PNE's per year might be required if this application became fully developed.[17]

Many problems plague both in-situ retorting processes. Some features that need to be researched are the percentage of oil that might be recovered (optimistic estimates are 60%), the extent to which the void space in the rubble might be closed by such phenomena as exfoliation of the rock, and the pressure drop through the length of the chimney (the pressure drop affects a critical cost element - compression of the air). Some experimental data is being provided by an experimental 150-foot retort created by non-nuclear techniques and operated by the Bureau of Mines. However, it is not clear how one should extrapolate these data to the much higher chimneys and perhaps different rubble-size distribution to be created by a nuclear explosion.

The behavior of the shale following a nuclear explosion is a major uncertainty as PNE's have never been tested in this unique medium. It is critical to predict accurately parameters such as the chimney height, void space (now estimated at 12½%), and rubble size.[18]
As in other PNE applications there would be some radiation and seismic effects. The surface rise might be appreciable and could affect such high–investment structures as processing plants for the shale oil.[19]

The application of nuclear explosions to recovering oil shale is restricted to a limited portion of the shale region by several siting requirements. The explosives must be used in beds with an overburden of at least

1000 feet to avoid venting of radiation. They must be spaced far enough apart to avoid a blow-by, in which the chimney created by one explosion interferes with that from another. This latter spacing requirement may mean that only 25% of the oil shale in a given region may be fractured by PNE's.[20] The retorting process in turn can extract at most 60% of the oil in the fractured shale, further reducing the yield.[21]

Prospects for above ground retorting now appear poor because of unfavorable economics and environmental impacts. In situ retorting using conventional explosives appears better on both counts, but is in a substantially earlier stage of development. If oil shale is to be exploited, one or both of these techniques will be utilized well before the PNE concept can be realized.[22]

Creation of Storage Cavities

The furthest developed application of PNE's is the creation of underground storage cavities. The first contained Plowshare explosion, dubbed Gnome, was a 3.1 kt blast in a salt formation that produced a cavern with few cracks and glazed walls. Such a volume could be used for storage of gas, oil, liquefied natural gas or even for permanent storage of chemical or radioactive wastes. Salt domes or salt formations are probably the best media for such cavities, although other rocks such as clay, clay shale or some sandstone may also be quite adequate. Hard rock tends to fracture into large cracks when subjected to nuclear explosions.

The usefulness of nuclear explosions for creating such storage chambers will depend in part upon the number of locations that can be found with just the right combination of circumstances: salt domes situated far from population centers but near strategic points with respect for the marketing or transportation of oil and gas. These requirements frequently conflict with one another.[24]

One alternative to nuclear-created storage cavities is to construct above ground containers of steel or concrete, but these are often more expensive than underground vaults created by nuclear means. Solution-washed salt cavities may be cheaper but they are limited to regions near salt water for washing and the ocean for disposal.[25] Perhaps the least costly alternative for storage is to use abandoned mines or aquifers. There may be enough of these at appropriate locations to eliminate the need to carve new caverns with nuclear explosions.[26]

Leaching of Copper Ore

A fifth beneficial application of nuclear explosions might be to assist in the mining of copper deposits. A nuclear blast could be used to fracture the copper ore to facilitate a leaching process. The ore is leached with water that is saturated with oxygen in order to convert the insoluble copper sulfides to soluble sulfates. The problem is to have the temperature high enough (around 200°F) and the circulation rapid enough for the sulfate to remain in solution long enough to be extracted. Research on using PNE's for this technique began in 1967 with Project Sloop and is now being conducted jointly by LLL and the Kennecott Copper Company.[27]

As in the case of in situ retorting of oil shale, uncertainties must be resolved concerning the non-nuclear as well as the nuclear aspects of the copper leaching technique. Some of the unknowns include the degree of oxygen saturation required, the temperature gradient (because of the reaction rate is a function of temperature) and the composition of the ore itself. Once these questions are answered one must determine the size and distribution of the rubble created in the ore by the nuclear explosion, which in turn affect the reaction rate and the speed of fluid flow.[28]

The seismic damage may rule out some applications of this technique because significant copper deposits are located quite near to populated areas.[29] Further restrictions might result from possible contamination of the copper with small amounts of ruthenium-106, an element with a half life of about one year. A final factor limiting the use of PNE's is that the economics will remain quite marginal unless the prices of copper rise.

These five applications for PNE's are only a few in a long list of proposals, but the others have received considerably less attention. No application is close to being realized in the U.S. In all cases there appear to be viable alternatives, but in some cases, PNE's seem to offer substantial cost savings. As illustrated above, however, a great many uncertainties must be resolved before commercial use can be contemplated.

USSR Program on PNE's

The Soviet interest in beneficial applications of nuclear explosions was increasing as that in the U.S. was declining. Some observers feel that the USSR may now be going through a period of questioning with regard to PNE's similar to that experienced by the U.S. ten years ago. Some representatives of the USSR over the past few years have expressed serious doubts about the prospects of PNE's.[30] Experiments are continuing, however, and at the August 1976 Conference on Complete Disarmament the Soviet delegate declared that "nuclear explosions for peaceful purposes represent one of the new and very promising avenues of the use of nuclear energy."

The outcome of any deliberations over engineering applications of nuclear explosions in the Soviet Union will depend upon the same types of factors as those in the U.S. but these factors may operate in different ways. The U.S.S.R. is unlikely to face severe public opposition to PNE's although environmental groups do exist (Such a group succeeded recently in changing the development plans for Lake Baikal.). The concern over the seismic damage and the radiation releases is not as great because the U.S.S.R. has vast unpopulated regions in which it envisions many of the proposed applications. The economics are difficult to evaluate as the U.S.S.R. has not published any studies and the accounting procedures may be very different.

The technical aspect of PNE's have as many uncertainties in the U.S.S.R. as in the U.S.[31] The Soviets do have an active experimental program and are investigating a wide variety of applications and types of geological materials. From 1965 through November 1973, the Soviets conducted 16 nuclear explosions which they claimed were for industrial or experimental purposes. (See Table 2.) An additional 17 seismic events have been identified (by either ERDA or by the Stockholm International Peace Research Institute) as nuclear explosions outside the normal weapons test areas; these events are classified as probable PNE tests.[32] Two such tests were monitored in 1976, the more recent being a blast in Central Siberia on November 5.[33]

U.S.S.R. Excavations

One of the applications of PNE's that has received much attention is the construction of a canal to link the north-flowing Pechora River with the south-flowing Kana River. The goal is to increase the water flow into the Caspian Sea, whose level has dropped in recent years because of dry weather and heavy water demand. The Soviets have proposed the use of nuclear explosives to dig a 65-km section of the 112.5-km canal that traverses the most mountainous terrain. This application calls for 250 explosives of up to 150 kt each. (See Table 3.) They have tested three 15 kt explosions in the water-saturated alluvium soil that forms part of the canal route. (The effect of nuclear blasts on the rocky portions are believed to be better understood.) The tests resulted in a crater that is perhaps shallower and smaller in cross section than planned, but the Soviets claim it is adequate for their canal.[34]

Another excavation project for nuclear explosions in the U.S.S.R. is the creation of water-storage reservoirs, especially in the Central Asiatic Republic.[35] One such reservoir was created by a nuclear blast of more than 100 kt that was set off adjacent to a river bed. The crater lip formed a dam across the river and a reservoir behind it. A canal was subsequently dug to connect the crater with this reservoir. In this test and others, the crater lip tended to slump following the explosions, creating a wider but shallower crater, but was stable thereafter.[36] The Soviets seemed pleased with this project but later let the water drain.[37]

A final excavation proposal is to remove the overburden from large deposits of non-ferrous metals. It is estimated that perhaps more than half of the deposit can be made accessible by nuclear techniques at a savings of over one billion rubles.[38] The area is described as being similar to the far north but with high seismicity and frequent earthquakes.[39]

These three plans for excavation experiments in the U.S.S.R. are remarkable if only because the U.S. has long since discontinued its excavation projects to comply with the Limited Test Ban Treaty. Indeed, the crater lip dam did produce fallout that travelled beyond the boundaries of the U.S.S.R.[40] The Soviets claim that the radiation releases fall below standards for radiation protection, but the limit set by the Treaty is zero. This risk is inherent to excavation projects. Continued Soviet violations may put a severe strain on the treaty.

USSR: Contained Applications

The Soviets are investigating several uses of contained nuclear explosions in the category of resource recovery. They have claimed success in increasing the production of two oil fields by a series of explosions of 8 kt or less (See Table 2.) They presented too little data for their claims to be verified,[41] but several U.S. observers feel that it is not clear that the production increases were the direct result of the nuclear explosions.[42]

The U.S.S.R. plans to use PNE's to simulate gas production as well. Although they claim to have conducted a test of this application, no details have been forthcoming.[43] The application of the fracturing properties of nuclear explosions to the breaking of ores is also being studied.[44]

As in the U.S., the application that is the most developed is the creation of underground storage chambers. The first cavity tested (created by 1.1 kt device exploded in a salt dome) leaked water and radioactivity. A second (25 kt in a salt dome) proved to have satisfactory storage properties. The third cavity (15 kt in salt formation) is now in industrial use for the storage of gas condensate.[45]

A proven but limited use for nuclear explosions that was developed in the U.S.S.R. is the sealing of runaway gas well fires. A 30 kt device sealed a fire that had been out of control for three years; a 40 kt explosions extinguished a flame in an adjacent well.[46] No other methods had been feasible or effective.

In the descriptions of all their various programs, the Soviets seem optimistic, but close examination reveals that few of the PNE uses (except perhaps the control of runaway gas well fires) are really proven both technologically and economically.

The intensity of Soviet interest in its PNE program is difficult to assess, especially as divergent voices are still expressed within the scientific community.

Most of the applications are being promoted more by technocrats than politicians. Which would win out if the U.S.S.R. ever had to decide whether it would forego the benefits of peaceful nuclear explosions in order to gain a comprehensive test ban? A very remote possibility is that the PNE program is being kept alive simply as an excuse not to enter into a complete test ban.

PNE Interest in Other Nations

Among the nuclear weapons states, the U.S. and the U.S.S.R. have by far the most active programs. France has expressed some interest in underground storage, especially under the ocean, and in the stimulation of hydrocarbon resources. However, she is limited from extensive PNE applications by her dense population. Great Britain faces similar limitations and has virtually no plans to use PNE's.[47] The plans of China are not known.

Although India claimed her nuclear detonation was a test for peaceful purposes, she has never elaborated in detail what her hopes for PNE's are. The Indian delegate to the IAEA technical meeting in 1975 spoke only vaguely about interest in stimulating production from oil wells (an application that is nearly rejected in the U.S.) and in the mining of non-ferrous metals.[48]

Among the non-nuclear nations, the most publicized peaceful applications of nuclear explosions are excavation projects. Perhaps these nations cannot think in terms of contained applications, which frequently would require hundreds of explosives per year and necessitate a reliable source of PNE's. Three canal-building proposals are summarized in Table 3. The Columbian project was considered the most favorable route evaluated by the Atlantic-Pacific Interoceanic Canal Study Commission. Little mention of it is made in recent literature.

Both Venezuela and Thailand have proposed canals that are estimated to be cheaper with nuclear than conventional explosions by significant margins” The Venezuelan plans involve smaller devices but would require the evacuation of two villages.[49] The Thailand project calls for very large blasts and would certainly spread radioactive debris to its neighbors. In addition, it requires the evacuation of 200,000 Thais for up to 16 months.[50] The feasibility study was financed privately under a previous government and the new government has adopted a very cautious attitude toward the canal project.[51]

The Egyptians have been investigating the use of nuclear explosions to help excavate 68 km of a canal that would link the Mediterranean Sea with the Qatarra depression. Water flowing from the sea into the depression could drive a 300 MWe (1200 Mwe peak) hydroelectric plant. The plans require some 213 explosions and evacuation of less than 25,000 people within 80 km of the route. Use of the nuclear explosions is estimated to reduce the total project cost by almost a factor of three.[52]

The likelihood of these or any other PNE proposals for non-nuclear nations depends strongly upon the resolution of technical uncertainties by research in the U.S. and U.S.S.R.[53] It also depends upon the need for the particular application, the availability of alternatives, the socioeconomic effect treaty provisions and the environmental impact.[54] If these factors were all resolved in favor of PNE’s, then institutional questions would arise regarding the source, cost and conditions of the nuclear explosives. 35 The suppliers of PNE’s are likely to be either the U.S. or the U.S.S.R., as they can presently manufacture the type and quantity of explosives required. However, other nuclear weapons states could quickly develop the technology to produce them as well.[56]

Conclusions

None of the proposed applications of nuclear explosions has been unambiguously determined to provide net benefits. Even the most optimistic estimates do not envision large scale applications in the near future. At the same time, few applications have yet been disproven. In the face of such ambivalence the present course has been to proceed with a low level of research on major uses of PNE's and move only slowly and cautiously toward providing PNE services to NPT signers.

One danger of this course is that the separate status accorded PNE's hinders progress towards a comprehensive test ban. The present course also provides justification for non-nuclear weapons states to develop nuclear explosives. Several seeds of discontent have been sown by PNE's: Many nations feel disappointed that earlier promises of PNE's have not yet been fulfilled. They also resent the reluctant pace at which provision for PNE services has been moving. For a nation such as Egypt, which has not ratified the NPT and which has proposed a PNE application, these feelings may contribute to a decision not to enter into the Treaty. Nonsigners may conclude they have more to lose than to gain by signing. Even if PNE's are not the real motive they might at least be the excuse for a nation to remain outside the NPT and even to develop their own nuclear weapon, as India has done.

One step out of the present course would be to call for a temporary ban on the conduct of all nuclear explosions for peaceful purposes.[57] Such a moratorium might be palatable in light of the findings of the GURC report that few applications of PNE's are likely to be feasible before 1980. Research on PNE's need not be halted along with the tests themselves because many non-nuclear aspects of each application need to be fully investigated.

The moratorium could be conditional upon either an unambiguous demonstration of a beneficial and viable application of PNE’s or upon the outcome of an international conference to assess the practicality of PNE technology at that future date. Other international conferences have dealt with various aspects of PNE technology but none has tried critically to evaluate and balance all factors--technical, economical, sociological, environmental and political.[58,59]

A permanent ban on PNE’s is a more drastic and perhaps premature step. The Soviets would be unlikely to accept it, even as a price for obtaining a comprehensive test ban, given their current announced interest in beneficial applications of nuclear explosions. Non-nuclear nations who have been led to believe in the real promise of PNE’s, may also object to such a proposal. They might justifiably claim it violates Article V of the NPT. Even in the U.S., industry seems to want to keep open the door for some possible far-future development of peaceful explosions.

A step in the opposite direction but aimed at the same result is to establish an international service to provide nuclear explosions for peaceful purposes to all nations, regardless of membership in the NPT.[60,61] This action might prevent non-NPT nations from developing nuclear weapons and labeling them peaceful devices. With an international service to provide PNE’s cheaply, no nation need make its own. Opponents of this plan argue that it is premature and that any sanctioned nuclear explosions makes a CTBT very difficult to achieve. The danger exists that such an institution as an international PNE service might be tempted to develop and promote various beneficial applications to justify its existence.

Any new course undertaken to deal with PNE’s must be charted to steer away from the three major dangers they now present: Hindering progress towards a CTB, retarding membership in the NPT and providing excuses for nations to test their own nuclear bombs. The present course runs into all three dangers. Each of the alternate routes avoids primarily one of the dangers. The proposed temporary ban on PNE’s would eliminate an obstacle to a CTB, while a provision for PNE services would remove the possibility that PNE’s could be used as an excuse. A decision between either of these courses then depends upon the area of greatest concern as well as upon the probable effectiveness and possible negative side effects of each action. The choice is not clear.

Footnotes

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TABLE I

PLOWSHARE CHRONOLOGY

L Program Milestones

Date	Event
Nov. 26, 1956	Commission approved in-house conference on peaceful uses of nuclear explosives. Lawrence Radiation Laboratory, Livermore (LRL-L), had been informally studying the question during previous years. (Staff Paper 81 1/4)
February 1957	First Plowshare Symposium held at LRL to discuss Industrial Uses of Nuclear Explosives."
June 27, 1957	Commission approved the establishment of a program in the Division of Military Applications to investigate nonmilitary uses of nuclear explosives. (Staff Paper 811/6, dated June 13, 1957)
July 1957	LRLL-L formalIy establish Project Plowshare to investigate the nonmilitary applications of nuclear weapons.
, September-1957	Project Rainier, the first US underground detonation of a nuclear exp!osive. A chimney of featured rock was formed which provided data on possible" underground engineering applications of nuclear explosions.
October 1957	The US Corps of Engineers agreed to supply support services for the Plowshare Program.
Dec. 10, 1957	'General Advisory Committee to AEC recommended that a study group be formed to investigate peaceful uses of nuclear explosives for the production of isotopes and for large earth-moving projects.
March 31, 1958	Responsibilities for operations and industrial contacts delegated to San Francisco Operations Office (SAN). SAN established Special Projects Group to oversee program.
July 1, 1958	Plowshare support efforts established at Albuquerque Operations Office (ALOO) and Oak Ridge Operations Office (OROO). "
Aug. i5, !958	US Geological Survey agreed to conduct support studies for Plowshare Program.
Sept. 9, 1958	US Bureau of Mines agreed to cooperate on Plowshare Program.
October 1958	US began voluntary moratorium on all nuclear testing.
Dec. 15,1958	Formation of Peaceful Nuclear Explosives Branch in DMA to supervise Plowshare Program.
January 1959	Joint AEC/Bureau of Mines Oil Shale Symposium at Dallas, Texas. Presented material on use of nuclear explosions to recover oil from oil shale.
May 13–15, 1959	The Second Symposium on the Plowshare Program was held in San Francisco, California, with 495 attendees. The symposium was open to the public including international participation.
November 1959	Sandia Laboratories Plowshare research and development effort established.
January 1960	In 1960 the Panama Canal Company reviewed and updated the 1947 studies in collaboration with the AEC.
August 1961	The Plowshare "Program was removed from DMA and the Division of Peaceful Nuclear Explosives established to administer the program.
September 1961	The US voluntary test moratorium of two years and 11 months duration was ended.
Dec. 10, 1961	Project Gnome, the first Plowshare experiment was conducted December 10, 1961. near Carlsbad, New Mexico. The explosive yield of this multipurpose experiment was 3.1 kt.
1962	US Corps of Engineers established Nuclear Cratering Group at LRL to cooperate with AEC on (1) projects concerning collateral high explosive experiments. (2) the development of engineering concepts relating to construction in fracture zones, and (3) studies of slope stability and related engineering considerations.
April 1962	The President requested the AEC and Corps of Engineers to jointly assess the feasibility of using nuclear excavation for canal construction. This led to the 1964 card studies.
July 1962	Savannah River Operations Office initiated support studies for Plowshare Program.
Sept.-Oct. 1963	Team of Australian scicntists visited US to review Plowshare Program and study the scientific. engineering and safety aspects of nuclear explosives.
October 1963	The Limitcd Test Ban Treaty was ratified by the Presidcnt, with conscnt of the Senate. The treaty prohibits nuclear cxplosions in the atmosphcrc, in outer space and under water.

from "PNE Activity Projections for Arms Control Planning" ACDA/PAB-2531 prepared for US ACDA by GURC.

also prohibits any underground explosion "which causes radioactive debris to be present outside the territorial of the limits of the state under whose jurisdiction or control the explosion is conducted."

April 21-23, 1964 The Third Plowshare Symposium, "Engineering with Nuclear Explosives," was held at the University of California, Davis, California. Several hundred visitors including representatives from the United Kingdom, France, Australia, Canada, Mexico, Switzerland, South Africa, Israel and the International Atomic Energy Agency attended.

May 1964 The US Atomic Energy Commission released a policy statement and projected charges for Plowshare thermonuclear explosives for use by industry in conducting studies of economic and technical feasibility:

10 Kilotons-S 350,000
2 Megatons-S600,000

Sept. 22, 1964 Public Law 88-609 was signed by the President "to provide for an investigation and study to determine a site for the construction of a sea-level canal connecting the Atlantic and Pacific Oceans," and authorized establishment of a Commission to carry out provisions of . the Act. The Atlantic-Pacific interoceanic Canal Study Commission was established on April 18, 1965, to study sites for construction of a sea-level isthmian canal connecting the Atlantic and Pacific Oceans, and methods of construction. Studies included the feasibility of excavating a sea-level canal with nuclear explosives.

Feb. 14, 1967 Treaty for the prohibition of nuclear weapons in Latin America was signed in Mexico City. The treaty establishes Latin America as an area in which the participating nations will not manufacture or otherwise acquire nuclear weapons (explosives), but permits these nations to collaborate with third parties such as the US for the purpose of carrying out nuclear explosions for peaceful purposes.

Dec. 10, 1967 Project Gasbuggy, the first cooperative industry-government experiment, was conducted on December 10, to investigate the use of a nuclear explosion to stimulate a low producing gas field. The nuclear explosion of approximately 29 kt., which occurred 4,240 feet [1,292 meters] beneath the earth's surface, created a chimney about 335 feet [102 meters] high and 160 feet [49 meters] in diameter.

March 8, 1968 The Commission assigned the technical direction for Project Rulison to Los Alamos Scientific Laboratory.

March 12, 1968 Project Buggy. the first nuclear row charge experiment. The explosion. which involved the simultaneous detonation of five, 1.1 kt. explosives placed 150 feet [45.7 meters] apart at a depth of 135 feet (41.1 meters], created a ditch 855 feet [261 meters] long, 254 feet (77.4 meters] wide and 65 feet [19.8 meters] deep.

April 14–16, 1969 The first of a series of US/USSR bilateral technical talks took place in Vienna, Austria, on "Peaceful Applications of Nuclear Explosions."

Jan. 14– 16, 1970 An "Engineering with Nuclear Explosives" symposium sponsored by the American Nuclear Society was held in Las Vegas, Nevada. Sixteen foreign countries participated or attended. France, for the first time, presented technical data on their "Plowshare" Program.

Feb. 11-17, 1970 The second US/USSR bilateral technical talks took place in Moscow on "Peaceful Uses of Nuclear Explosions." The talks, just as those in April 1969, were restricted to technical aspects.

March 5, 1970 The Nonproliferation Treaty was put into force. Article V of the Treaty pertains to making available to non-nuclear-weapons states any benefits from peaceful uses of nuclear explosions.

March 2-6, 1970 An IAEA panel meeting on the peaceful uses of nuclear explosives was held in Vienna, Austria. The participants included France, Japan, Sweden, Australia, India. USSR, United Kingdom, and the US. At this meeting the Soviets, for the first time in public, discussed the USSR "Plowshare" Program which goes by the title, Nuclear Explosives for the National Economy,"

March 16. 1970 The Rulison Court decision, by the US District Court *for* the District of Colorado (Judge Alfred A. Arraj) ruled that: the flag phase of Project Rulison does not present a threat to public health and safety: the AEC has planned its activities and is curry in: them out with all due regard for health and safety: and radiation dose from flaring will be within radiation Standards.

Dec. 1, 1970 — The Atlantic-Pacific interoceanic Canal Study Commission transmitted to the President its find report on December 1, 1970, and stated: ". . . although we are confident that someday nuclear explosions will be used in a wide variety of massive earth-moving projects, no current decision on US canal policy should be made in the expectation that nuclear excavation technology will be available for canal construction. . ." It was recommended that ". . . the US pursue development of the nuclear excavation technology, but not postpone Isthmian Canal policy decisions because of the possible establishment of feasibility y of nuclear excavation at some later date."

11. Contained Experiments and Study Projects Related to Industrial Applications

Date	Project or Study
September 1957	Rainier-The first US underground detonation of a nuclear explosive. This weapons test formed a chimney of broken rock which provided data on possible underground engineering applications of nuclear explosives.
August 1960	Pinot-HE experiment in oil shale near Rifle. Colorado.
Nov. 5,1964	Handcar-Plowshare nuclear explosion experiment Yield–12 kt. Depth of Burial-1,320 ft [402.3 m]. Medium-dolomite (carbonate rock) Site–Nevada Test Site Chimney dimensions-radius 69 ft (21 m]; height 233 ft [71 m] Objective-Study effects of nuclear explosions in carbonate rock.
Dec. 6,1966	Project Dragon Trail Study–Joint natural gas stimulation experiment proposed by Continental Oil Company and CER Geonuclear. In May of 1969, Continental advised the AEC that they did not plan to move forward in this project because of the added expense of drilling to greater depths than they planned. Also they felt the information from Gasbuggy and Rulison would answer many of their questions.
August 1967	Project Ketch Study–A joint feasibility study begun in 1965 was completed by the Columbia Gas System Service Corp., US Bureau of Mines, Lawrence Radiation Laboratory, and the San Francisco Operations Office-AEC to study uses of nuclear explosives to create underground natural gas storage reservoirs. The study was followed by a proposal from Columbia Gas to the AEC to conduct a joint experiment to further investigate this application. However, in 1968 Columbia withdrew the request for state land in Pennsylvania to look for other sites. It is informally understood that the Company has decided to defer further action.
Oct. 24, 1967	Project Bronco Study–A joint feasibility study begun in 1966 was completed by CER Geonuclear, representing some 20 oil companies, the Lawrence Radiation Laboratory, the US Bureau of Mines, and the San Francisco Operations Office to study the use of nuclear explosions to fracture oil shale for subsequent recovery of the oil by an *in situ* retorting process. The study resulted in a proposal from CER on behalf of the oil companies to conduct a joint experiment to test this concept. Although a contract was negotiated in 1968, it was not accepted by the oil companies. No further action is anticipated regarding this particular project although studies respecting nuclear application with oil shale continue.
Dec. 10, 1967	Project Gasbuggy-A first Plowshare joint government-industry nuclear experiment to test out an industrial application. Participants-El Paso Natural Gas Company, Department of interior, Atomic Energy Commission Technical Director-Lawrence Radiation Laboratory Yield–29 kt. Depth of Burial-4,240 ft [1,292 m]. Medium–Sandstone, gas bearing formation Chimney dimensions-height 335 ft [102 m], radius 80 ft [24.4 m] Site San Juan Basin, New Mexico

Objective-To investigate the feasibility of using nuclear explosives to stimulate a low producing gas field.

Sept. 1O, 1969 Project Rulison - A joint government-industry gas stimulation experiment
Participants Austral Oil Company. CER Geonuclear Corporation (program manager). Department of Interior. Atomic Energy Commission
Technical Director Los Alamos Scientific Laboratory
Yield 40kt.
Depth of Burial 8,425.5 ft [2.568, lm]
Medium Sandstone, gas bearing formation
Chimney dimensions --height 270 ft [82.3 m], radius 70 ft [21.3 m]
Site -Garfield County, Colorado
Objective- To investigate the feasibility of using nuclear explosives to stimulate a low-producing gas field.

Proposed Experiments

Oct. 25, 1967 Reject Sloop-A joint feasibility study begun in 1965 by the Kennecott Copper Corporation, US Bureau of Mines, Lawrence Radiation Laboratory, and the San Francisco Operations Office-AEC to consider the overall feasibility of using nuclear explosives for fracturing low-grade copper ore bodies for subsequent recovery of copper by conventional *in situ* leaching methods was completed. Upon completion of the study. Kennecott-Copper Corporation proposed a joint experiment to the AEC to test this concept. The company is re-evaluating the project with regard to the current price of copper vs. the lack of available funds in both government and industry.

Jan. 24.1968 Wagon Wheel–This is a Plowshare gas stimulation project in the Pinedale area of Wyoming to demonstrate stimulation of formation at depths of 10,000 to 18,000 feet [about 3,000 to 5,500 meters] . meters]. The industrial sponsor, El Paso Natural Gas Co., has entered into the project definition stage. Execution is planned in late 1972 or early 1973.

July 30, 1969 WASP- A joint venture of companies and individuals interested in a Plowshare gas stimulation project in the Pinedale area of Wyoming. Oil and Gas Futures, Inc., of Bellaire, Texas, is the operating company for this group. The project is currently in the project definition stage. The project execution date is not expected before 1973 or 1974.

Dec. 18.1970 Rio Blanco-The feasibility study prepared by the industrial sponsor (CER Geonuclear, who is using lands obtained under joint venture agreement with the Equity Oil Co.) was accepted as a basis for entering into joint project definition activities with CER. This is to be a gas stimulation project in western Colorado, possibly using two or more nuclear explosives in the same emplacement hole. Execution is planned for late 1972.

TABLE II

Soviet excavation PNE applications.

Water Resource Development:		
1003	1-1 kt	Cratering shot in siltstone.
1004	125 kt	crater in river produced two lakes, 1° 6 x 10 m (13, 000 acre-ft) "Proven "Proven Technology".
Proposed reservoir	Two 150-kt	To form 3 x 10^7 m (24, 000 acre-ft) reservoir.
T-1	0-2 kt	Cratering shot in sandstone calibration for T-2.
T-2	Three 0-2-kt	Row-charge cratering shot "model of Pechora-Kama".
Proposed Pechora-Kama Canal	250 explosives	Divert Pechora River into Kama River and *thence* to Caspian Sea.
Pechora-Kama row crater	Three 15-kt	Experiment at southern end of Pechora-Kama Canal alignment to gain data on cratering characteristics and stability in saturated, alluvial medium.
Overburden Removal:		
Proposed mining project	-1-Mt row charge	Will remove 900,000 m^3 of overburden at 5 kopecks/m^3

Soviet contained PNE applications.

Application	Explosives	Comments
Control of Runaway Wells:		
Urtabulak	.30 kt	$75 million lost over 3 years
Nearby gas field	40 kt	"Proven Technology"
Oil Stimulation:		
Field A	Two 2-3-kt + ore 8-kt	26% internal rate of return in U.S.
Field B	Two 8 kt	"Proven Technology"
Proposed Field C	Three 20-30 kt	Designed to break barrier so underlying water will push oil out
Gas Stimulation:		
Underscribed	.	Statement that such an application was carried out
Proposed gas condensate field	Three 40-kt	Expect increase from 7-5 x 106 to 100 x 106 ft 3/day
Underground Storage of Oil or Gas:		
Salt Dome A	1-1 kt	Salt dome - leaked water and radioactivity
Salt Dome B	25 kt	106 -bbl storage at 1/6 surface gas storage and 1/3 washed cavities cost
Unidentified cavity		Tested with oil and gas at 6 MPa (50 atm)
Gas condensate storage facility	15 kt	300, 000-bbl storage facility in industrial use at a gas condensate deposit -- working pressure 8 MPa (80 atm)
Proposed - layered salt	TwO 35-kt	Require 2 x 10^6-bbl storage for gas condensate
Proposed - tuff uncle? permafrost	Three 40-lit	Require 2-5 x 10^9 ft^3 storage for gas at 7 MPa (70 atm)
Mineral Development:		
"Granddaddy Shot"	1 kt	Granite shot similar to Hardhat
Proposed ore breaking	1-8 kt	-Will break -10^6 m^3 of ore in situ

"A Review of Soviet Data on the Peaceful Uses of Nuclear Explosions" by Milo Nordyke (LLL), Ann. Nucl. Energy Vol. *2, pp. 657-673, Pergamon* Press 1975.