Peaceful Nuclear Explosions

Article V of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) specifies that the potential benefits of peaceful applications of nuclear explosions be made available to non-nuclear weapon states party to the Treaty "under appropriate international observation and through appropriate international procedures".

The International Atomic Energy Agency's responsibility and technical competence in this respect have been recognized by its Board of Governors, the Agency's General Conference[1] and the United Nations' General Assembly[2].

Since 1968 when the United Nations Conference of Non-Nuclear Weapon States[3] also recommended that the Agency initiate the necessary studies in the peaceful nuclear explosions (PNE) field, the Agency has taken the following steps:

1. The exchange of scientific and technical information has been facilitated by circulating information on the status of the technology and through the Agency's International Nuclear Information System. A bibliography of PNE-related literature was published in 1970[4].

2. In 1972, guidelines for "the international observation of PNE under the provisions of NPT and analogous provisions in other international agreements" were developed and approved by the Board of Governors[5]. These guidelines defined the basic purpose of international observation as being to verify that in the course of conducting a PNE project the intent and letter of Articles I and II of the NPT are not violated.

3. In 1974, an advisory group developed "Procedures for the Agency to Use in Responding to Requests for PNE-Related Services"[6]. These procedures have also been approved by the Board of Governors.

4. The Agency has convened a series of technical meetings which reviewed the "state-of-the-art". These meetings were convened in 1970, 1971, 1972 and in January 1975[7].

The Fourth Technical Committee was held in Vienna from 20 – 24 January 1975 under the chairmanship of Dr. Allen Wilson of Australia with Experts from: Australia, France, Federal Republic of Germany, India, Mexico, Sweden, Thailand, United Kingdom, USA and USSR. An additional 21 Member States sent observers. A summary of the technical papers follows:

In general, statements on national programmes revealed continued interest in assessing the technical and economic feasibility of peaceful nuclear explosions and in evaluating the health and safety problems. In some cases the interest was qualified by the realization

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1 GC XIII/410
2 GA/Res. 2829(XXVI)
3 United Nations document A/7277 Res. H.IV and H-1
4 IAEA Bibliographical Series No. 38 (1970)
5 Document INFCIRC/169
6 Document GOV/1691
7 The proceedings of the first three meetings have been published as IAEA publications STI-PUB-273, 298 and 367. The proceedings of the fourth meeting will be available before September 1975.

that factors such as high population densities and social attitudes make it improbable that the States concerned will be able to make any use of peaceful nuclear explosions domestically even if such explosions are shown to be technically and economically viable. Health and safety, phenomenology, applications, and projects all received attention in the technical papers presented by participants. The scope of the health and safety papers and the discussion which they generated reflected the considerable attention now being given to these aspects both within and outside of national programmes.

BASIC PHENOMENA

The discussion of explosion phenomena and of the scientific basis for some of the physical and mechanical effects observed showed that there is still considerable opportunity for new and meaningful work in these areas. Three papers concerned themselves with these matters, as shown below:

(a) Mr. Rodionov (Soviet Union) presenting paper TC-1-4/15 pointed out that the residual displacements and their associated stresses following a nuclear explosion are superimposed on the tectonic stress of the rock massive thus changing the stress distribution over a significant area. He suggested that such a modification might be utilized in a mining application or in changing the ease with which certain minerals might be recovered;

(b) The importance of being able to predict rock fracturing was emphasized by Mr. Rodionov (Soviet Union) in presenting paper TC-1-4/16. He detailed results from chemical explosive laboratory experiments in which the relation between the shock front and the fracture front in resin was measured at various shock pressures;

(c) Mr. Prieto (Mexico) in presenting paper TC-1-4/11 showed that the basic shock equations can be transformed by means of dimensionless variables into expressions which are numerically valid for a variety of solid materials and provide added insights into their behaviours under shock loading.

HEALTH AND SAFETY

A number of papers were presented on potential health and safety problems of both contained and excavation PNE applications, with particular emphasis on radiation. In paper TC-1-4/7, Mr. Schwartz (United States of America) described in detail the chemical and physical state of the radionuclides produced in most contained situations and discussed the various pathways by which the exposure of man to radiation could occur: seepage of radioactivity to the surface shortly after the detonation through fractures associated with drill holes; release of gases during and subsequent to re-entry; occupational exposure of project workers; longterm migration of radioactivity into local ground water; population exposure to products containing radioactivity. Mr. Rohwer (USA) in paper TC-1-4/8 described a generalized computer-code methodology which can be used to assess, in relation to the recommendations of the International Commission on Radiological Protection (ICRP), the total dose to man from PNE explosions by any pathway or combination of pathways. Paper TC-1-4/7 examined each potential pathway, assuming significant industrial utilization of three technologies: nuclear gas stimulation, in situ copper leaching, and in situ oil shale retorting. It was concluded that, with all three technologies, radioactivity in the product was the pathway which gave the highest potential exposure in terms both of individual exposures to the general public (approximately 1 mrem/year), and of total population exposure (2000-20 000 man-rem/year); both these exposure levels are less than 1% of background. These potential exposures due to the use of natural gas extracted following nuclear stimulation in the above study are consistent with the findings of a much more detailed study presented by Mr. Rohwer (USA) in paper TC-1-4/3, which analysed the multiple potential pathways for population exposure, including the use of gas not only for domestic and industrial heating but also in food preparation, plastic and fertilizer production and intake food consumer products.

Mr. Schwartz (USA), presenting paper TC-1-4/9, gave a typical radionuclide source for nuclear excavation explosions and discussed the general methodology involved in calculating the transport of radioactivity from the explosion to its ultimate fate. The key elements in the process are the fraction of the radioactivity vented, the meteorological processes by which the radioactivity is transported through the atmosphere and deposited on the earth, and finally its passage through the appropriate food chain. As described by Mr. Petrov (Soviet Union) in paper TC-1-4/17, long-range air concentrations and deposition densities are determined by well-known atmospheric diffusion processes and can be calculated with accuracies of a factor of 5 or better for distances of many thousands of kilometres if atmospheric conditions are known. Examples of comparison between calculation and experiment were presented for dry deposition out to several thousand kilometres (project "1003"). Wet deposition or rainout was identified as a very important mechanism in paper TC-1-4/17 and TC-1-4/10, presented by Mr. Petrov (Soviet Union) and Mr. Knox (USA) respectively, since it can increase local radionuclide deposition by an order of magnitude or more with a proportionately higher local dose. Mr. Schwartz (USA) in paper TC-1-4/9 gave an example in which the above methodologies were used to calculate both the close-in fallout pattern and the long-range radionuclide deposition rate for a specific nuclear excavation project, the Kra canal in Thailand, utilizing local food chains for calculating the potential dose to man. Only tritium was found to contribute significantly to the world-wide dose (a total individual dose commitment of approximately 0.1–0.2 mrem). Recognizing that long-range radioactivity from nuclear excavation projects is a matter for concern, Mrs. Grechushkina (Soviet Union) proposed in paper TC-1-4/2 the formulation of standards for such projects, based generally on the recommendations of ICRP, and suggested the following three criteria for the maximum dose to large population groups at long ranges:

(a) The maximum dose should be a small fraction (5-10%) of the ICRP genetic 30-year dose of 5 rem and should be governed by the ICRP dose limits for critical organs;

(b) The genetic and specific organ dose limit should be small compared to that for radioactivity from natural sources; and

(c) The ^{90}SR and ^{137}Cs deposition rates should be limited so as not to increase the present average levels of these radionuclides in the northern hemisphere between the 20° and the 70° latitudes (the aim should in fact be to preserve the present trend toward a reduction of these levels).

A number of papers contained data on ground motions to be expected from PNEs. Potential damage from ground motions was recognized as the principal limitation on yield and therefore on the economic potential of PNE applications.

APPLICATIONS

Mr. Parker (United Kingdom of Great Britain and Northern Ireland) in paper TC-1-4/12 reported on a recent study concerning the applicability of a number of PNE ideas for storing and recovering natural resources from beneath the sea bed. The study concluded that, whilst limited opportunities may exist for sea bed applications in mineral recovery and gas storage, the use of PNEs for assisting with the production of oil and gas from deep sea locations constitutes by far the most interesting possibility. The significance of production stimulation techniques and "at sea" storage developments can be expected to grow as off-shore petroleum exploration progresses. Mr. Parker's study reviewed the advantages offered by PNE techniques along with the questions that must be answered before such an application could be seriously considered for industrial use. Potential reductions in the time required to construct an "at sea" storage facility are seen as being of prime importance.

Paper TC-1-4/2 presented by Mr. Lewis (USA) and paper TC-1-4/6 presented by Mr. Hard (USA) examined applications where permeable rubble chimneys would be utilized for further processing of the rubble in situ. The technical and economic viability is dependent therefore on the post-shot process as well as the PNE detonation. Both papers acknowledged the need to compare the potential of the PNE technique with existing and likely future development of alternative technologies capable of achieving the same objective.

In the case of the shale oil recovery application described by Mr. Lewis, air is introduced into a nuclear chimney of shale rubble. In situ combustion of a part of the organic material in the shale releases oil which is collected and pumped to the surface. Changed economic circumstances and acknowledgement of the difficulties posed by such environmental problems as the spent shale disposal required by conventional mining and retorting techniques have prompted a re-examination of the PNE alternative. It appears that the total environmental disruption resulting from a nuclear in situ process is potentially very much smaller than for any process requiring the mining of oil shale.

The copper recovery application described by Mr. Hard envisages the formation of a nuclear chimney in a low grade primary deposit below the water table. Bubbling oxygen through the chimney leads to the exidation of primary sulphides, the formation of sulphuric acid and dissolution of the copper. The paper uses the development of a hypothetical ore body to carry through an economic analysis of the application which suggests that the PNE technique may be the only economically viable means of recovering such resources. Potential radiation exposures do not appear to present insuperable problems and seismic damage may pose the main limitation to use of the techniques in populated areas.

PROJECTS

A preliminary assessment of the feasibility of using PNEs to assist in the excavation of a canal across the Kra Peninsula was outlined by Mr. Srisukh (Thailand) in his presentation of paper TC-1-4/1. Further studies are required in respect of the scaling of cratering parameters from the kiloton to the megaton region, local geology and hydrology, nuclear explosion phenomenology in limestone, seismic damage estimates, drilling under local conditions and radioactive pathways specific to local food chains. With these limitations in mind it was estimated that some two billion US dollars could be saved by using PNEs. Excavation of the canal using only chemical explosives is estimated to cost approximately six billion US dollars.

Not more than 200 000 local inhabitants would have to be evacuated for about one year at a cost considered trivial in relation to the total project cost. With a maximum charge yield of one megaton seismic damage could be a controlling effect with slight damage extending out to about 200 kilometres. The proposed excavation schedule envisages several salvoes of 5 megatons. The most favourable meteorological conditions for limitations of fall-out exposures are expected to occur on about four days a year.

An evacuation area determined by an 0.17 rem lifetime dose with re-entry after six months would be contained in Thailand. Estimates of long range cloud travel indicate total exposures of 15 and 1 milliroentgen for the Nicobar Islands and Sumatra respectively. The natural background exposure in these regions is about 100 milliroentgen per year.

Safety in Thailand and neighbouring States would be a foremost consideration. It was stated that the Government of Thailand probably would not authorize any PNE use in its territory without safety assurances from the supplier State or States and the consent of neighbouring countries.

Mr. Chidambaram (India), presenting paper TC-1-4/19, described a peaceful nuclear explosion carried out in 1974 along with its immediate physical consequences especially in regard to doming, cratering, ground motion, containment of radioactivity and the post-shot re-entry. Oil reservoir stimulation and non-ferrous metals mining were cited as promising future applications in India.

The plutonium device was emplaced at 107 metres below surface in nearly dry shale. A dome uplift occurred without radioactive venting. The dome collapsed to form a shallow crater. Radioactivity above the natural level was not seen in measurements out to some 20 kilometres downwind in the east-north-east direction. Emplacement, meteorological and radiological surveillance were described in some detail and also seismometric measurements, from which the yield was estimated. Re-entry drillings are under way. Special attention could be given to the phenomenology of this event as a contained, but doming and cratering explosion.

A survey of the operational aspects and the technical results of the USA's Rio Blanco gas stimulation experiment demonstrated the success which has attended efforts to develop nuclear explosives and firing techniques designed to meet the specific requirements of gas stimulation. In presenting paper TC-1-4/4 Mr. Nordyke (USA) described how the three 30-kt nuclear explosives used in Rio Blanco were emplaced through a conventional 27-cm diameter bore hole. The paper discussed the remote detonating and monitoring system which required only a modest amount of equipment. The top chimney was re-entered through the original emplacement hole although the bottom portion of the re-entry well had to be drilled through rock before connection with the chimney was established.

An evaluation of the Rio Blanco experiment was given by Mr. Holzer (USA) in presenting paper TC-1-4-/5. Tritium production was reduced by a factor of 10 in comparison with the Rulison device. Chemical analysis of the gas has established that the expected fracture interconnection did not occur. The reason for this departure from the fracture behaviour predictions of Terhune is not apparent and considerable further investigations of such factors as the fracture behaviour of rocks subject to simultaneous shock from two directions is called for. It was pointed out that inability to achieve interconnection is not of overriding economic importance as the fracture systems can be interconnected by a conventional bore hole which may increase the cost of the gas product by 20%. Gas flow from the upper chimney of the stimulated well has been disappointing. While the reasons for this are not entirely clear, the most likely explanation seems to be an overestimation of the capacity of the original reservoir.

In presenting paper TC-1-4/14 Mr. Myasnikov (Soviet Union) reported results from a Soviet nuclear cratering event carried out as a preliminary step in studying the use of nuclear excavation to construct a section of the proposed Pechora-Kama Canal. The Soviet experiment involved a row of three 15-kt nuclear charges fired in a weak water saturated alluvium near the southern end of the section proposed for nuclear construction. The experiment was designed to study the cratering characteristic of the medium and the stability of the crater slopes. A water filled crater trench adequate for use as an integral part of the ultimate canal was formed. The slopes of this water have been stable since the crater was formed.

The Soviets have constructed a gas condensate reservoir by means of a 15-kt nuclear explosion at a depth of 1140 metres in a bedded salt formation. Details of the project were given by Mr. Myasnikov (Soviet Union) in his presentation of paper TC-1-4/13. The cavity formed by the explosion has a volume of 50 000 m^3 (300 000 barrels) and was tested with gas and fluid up to a pressure of 84 bars to measure its size and to assure its integrity. The cavity was subsequently put into industrial use as part of the development of a gas condensate reservoir, eliminating the necessity of constructing expensive surface processing and storage facilities. The radioactivity in condensate stored in the cavity was reported to be below applicable radiation standards.

CONCLUSIONS

On the basis of the work of the meeting, the Technical Committee reached a number of conclusions, which are presented below. In considering these, the technical concepts outlined in the papers presented to the meeting should be borne in mind.

Well developed and tested modelling methods are now available for the prediction of the radiological health and safety implications of PNE projects. If the Agency wishes to place itself in a position to speak authoritatively on health and safety aspects of PNEs it should give early consideration to the selection of appropriate models and methods for use by its consultants and staff.

Meaningful discussion and analysis of large cratering projects requires the definition of accompanying radiation exposures, particularly those from long distance fallout levels. A useful area of activity for the Agency might be to seek to develop possible technical bases which could be used in quantitative studies of the health and safety aspects of such projects.

In many applications currently under evaluation seismic damage is seen to be a critical limiting factor. Improvements in the reliability of forecasting seismic damage could be of considerable significance. The attention given to seismic forecasting in international discussion to date has not been commensurate with the amount of data now available and the Agency might usefully consider facilitating information exchanges in this area.

Interest in PNE results within the scientific community at large frequently extends beyond their immediate relevance to PNE application, often in quite unexpected ways. Thus it is worth while publishing or making available all such data even if they do not bear directly on PNE applications. With this in mind the Agency might consider urging its Member States to go as far as practicable in releasing scientific results on peaceful nuclear explosions whether or not such results appear to be relevant to current PNE interests.

Recent experimental results indicate that the behaviour of rock in the region between simultaneous explosions may pose special problems from a rock mechanics point of view. Understanding the degree of fracturing and permeability of this region may be important to the economic attractiveness of several PNE applications. Therefore, the Agency should encourage additional fundamental research in this area.

The possibility of using PNEs for storage of petroleum liquids appears of considerable interest to many participants, especially if such storage could be developed off shore under the sea bed. Exploring the technical, environmental, and economic aspects of such storage could be a topic appropriate for future Agency activities.

An important aspect of the economic evaluation of possible industrial applications of PNEs is a fair comparison with the merits of approaches involving alternative technologies. In developing machinery for dealing with its PNE responsibilities, the Agency might consider how such comparisons could be made available to it and interested Member States.

It would be appropriate for the Agency to continue with the regular pattern of technical meetings which it has established.

FUTURE AGENCY PNE ACTIVITIES

In the committee's conclusions emphasis was placed on the health and safety aspects and consideration is given to such matters as the economics of PNE and alternative technologies, the prediction of seismic effects and the application of PNE for creating storage volumes for petroleum products.

On the basis of these conclusions and those of the first three technical panels, the Agency is now in a position to concentrate its work on specific technical areas. This work will include:

(a) The convening of a meeting of consultants in late 1975, to consider the health and safety aspects of PNE in order to be able to evaluate the merit of various predictive models and to consider possible technical bases which might be used in quantitative studies;

(b) The convening of a meeting of consultants to review the economic status of PNE and alternative technologies probably in early 1976; and

(c) The convening of a fifth technical meeting, probably in late 1976 which will place special emphasis on the forecasting of seismic effects and the application of PNE for the underground storage of petroleum products.