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# ENGINEERING WITH NUCLEAR EXPLOSIVES

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# NUCLEAR EXPLOSIVE DEVELOPMENT

[redacted]
Lawrence Radiation Laboratory, University of California
Livermore, California 94550

## Introduction

The nuclear explosive itself is the point about which the Plowshare program revolves. The energy potential of a thermal neutron fissionable material such as $Pu^{239}$ or $U^{235}$ of $\sim$17 kt/kg or of $Li^6D$ of $\sim$60 kt/kg is indeed impressive. Such large energy densities allow many applications for nuclear explosives that are unthinkable for conventional high explosives.

This country has been involved in the design of nuclear explosives for almost thirty years. A question often asked is, "Why do we still need design effort on nuclear explosives? Hasn't all the possible design work been done?". In a partial reply, let me give an analogy. Why work on nuclear reactors? They were successful even before the first explosive worked. Why should new accelerators be designed? They have worked for many decades.

The obvious answer to these questions is that new data, new theories, new insights into the problems and thus new possibilities are found and new requirements are continually being formulated. The development of larger and faster computers has allowed an enormous increase in the design calculations for nuclear explosives. Approximations in the physics involved in the calculations must be made in order to obtain solutions in a finite time, but these approximations can be made more accurately as the computing capability increases. Additional calculational capability also allows the designer to examine his design under a variety of possible conditions and configurations. The net effect is a much more sophisticated design. New developments in the area of materials and material properties open doors that have hitherto been closed. We have seen an increasing emphasis on the interaction of the explosive with its environment. Very specific applications require tailored features such as low fission yield, low fusion yield, low residual radioactivity in particular species, small diameter, low weight, low cost, etc.

The Plowshare program in particular imposes stringent requirements on the design of the nuclear explosive since the explosive is to be used in a peaceful environment with the safety of life and property as foremost requirements of the project. In addition, a Plowshare program must eventually compete economically with programs based on conventional sources of energy.

## Characteristics of Nuclear Explosives

In the design of a nuclear explosive, two general forms of energy release are available. These are the fission of a heavy nucleus or the fusion of light nuclei. The source of the energy release is clearly demonstrated by a plot of the average binding energy per nucleon as a function of mass number. Both fission and fusion reactions move the resulting mass numbers toward the maximum value of average binding energy per nucleon. Of course, the binding energy is not the only

consideration in these reactions. Detailed examination of nuclear properties shows the best isotopes for fission considering reaction cross section, material availability and material properties are $U^{235}$ and $Pu^{239}$, while the best candidates for fusion are the two heavier isotopes of hydrogen, i.e. deuterium and tritium. Tritium can be produced during the explosion by a neutron reaction with $Li^6$ so $Li^6D$ can be a fuel for nuclear explosives. The physical characteristics of an explosive (such as size, weight, residual radioactivity, interaction with the environment, neutrons emitted, etc.) depend in great measure on the source of the energy.

Tradeoffs are possible in the design area, and explosives can be tailored to some extent for specific applications. Each desired characteristic can usually be traded-off with other characteristics. For example, the diameter of the explosive can be reduced, but at the cost of increased usage of the fuel materials — which means increased dollar cost. The weight can be decreased with an increase in cost. The residual radioactivity can be reduced with an increase in cost and/or diameter. Because these trade-offs are possible, it is necessary to view the entire operation in which the explosive is involved and minimize the total cost — not just reduce costs in one particular area. For example, it doesn't make sense to drill a smaller diameter hole for a savings of $100,000 in drilling costs if the smaller explosive will cost $200,000 more. It also may not make sense to use a smaller diameter explosive if the clean-up of the additional post-explosion radioactivity costs more than drilling a larger diameter hole. An over-all systems approach is needed in order to present the most economical approach to Plowshare applications.

Because we cannot share all the details of our trade-off information with industrial concerns, it is doubly important that they supply the design laboratories with the results of their analyses. If we have good information on their costs (for example, drilling costs) and their assessment of the problems associated with radioactivity, then we as explosive designers are better able to make rational decisions as to the particular design characteristics to emphasize at this point in time. Since we cannot develop a new Plowshare explosive for each experiment, we must make reasonable compromise decisions and proceed with them. It is desirable that some methods of communication on a classified basis be found.

## Plowshare Applications

Plowshare applications fall into three general categories; excavation, underground engineering, and purely scientific. In figure 1 I've noted some characteristics of the ideal Plowshare explosive. These are not quite the ideal characteristics since the ideal explosive leaves no residual radioactivity, is infinitesimally small and light, costs nothing, and has a yield which is continuously selectable from zero on up — before, during and after the detonation. Ignoring these characteristics of the ideal "ideal Plowshare explosive", let me call your attention to the real, ideal explosive.

For excavation, the explosive should leave minimal radioactivity in the crater and fallout areas. This leads to the requirement of minimum fission yield and maximum fusion yield since the fission products contribute very heavily to residual radioactivity. Diameter and weight are not particularly serious problems. It is important that few neutrons be allowed to enter the soil since soil activation could produce a significant part of the total radioactivity.

REQUIREMENTS ON PLOWSHARE EXPLOSIVES

EXCAVATION
- Minimal Post-Explosion Radioactivity
  - Low Fission
  - Minimum Number of Neutrons to Soil
- Reasonable Cost
- Reliable

UNDERGROUND ENGINEERING (Hydrocarbon Stimulation)
- Minimal Post-Explosion Gaseous Radioactivity
  - All Fission
  - Minimum Number of Neutrons to Soil
- Minimum Diameter Consistent With Cost
- Environmentally Hard
- Reliable

SCIENTIFIC (Heavy Element Production)
- Large Neutron Fluence

Figure 1

For underground engineering, fission products (except for $Kr^{85}$) do not generally appear to be troublesome, but tritium from either the explosive or neutron reactions with trace lithium in the soil is quite a problem where hydrocarbons are involved. Calculations show that approximately 3% of all neutrons which escape into the soil will produce tritium in typical shales. In addition, tritium might be produced in second order reactions if boron is used as a shielding material. Thus for hydrocarbon applications a fission explosive should be used, but with no neutrons allowed to leak to the soil. Diameter might be a serious problem, but device, emplacement, and product utilization costs as a function of diameter must be considered together. The environment seen by this explosive can become quite harsh as evidenced by the current estimate of hydrostatic pressure up to 20,000 psi and temperature up to $450^{0}$F at maximum depth. To protect against these conditions requires part of the available diameter, and thus the environment is a serious constraint on the device design.

The scientific applications thus far pursued by Plowshare relate primarily to attempts to produce very heavy elements by multiple neutron captures in heavy nuclei. These require an explosive which will produce a very large, low energy neutron flux. Another application has been an experiment to measure neutron cross section using the nuclear explosive as the source of neutrons. Device diameter, weight, and cost are secondary concerns for such applications.

## Current Status and Future

The current status of specific explosives for these purposes may be described as follows.

A. Excavation

The majority of our design effort for the past few years has been devoted to an explosive for excavation purposes. Several tests at the Nevada Test Site have shown the device to be very reliable. Currently we are redesigning several parts of the device to further reduce the residual radioactivity. If the tests of these changes are successfully executed as

scheduled, by the summer of 1970 we will have a design which we are confident can provide any yield desired for excavation purposes. Both residual explosive and soil-induced radioactivity would be at very low levels compared with those expected from a fission explosive. For example, we would be able to provide a 1-Mt crater which would permit, according to the dose criterion of 5r per year or 3r per 3 months, permanent living on the crater lip soon after detonation. This explosive would weigh approximately 15 tons and would measure about 50" in diameter.

B. Underground Engineering

Even though there are several areas of interest in underground engineering, I've directed my remarks to explosives for use in hydrocarbon applications. To this time, the AEC has not developed an explosive tailored to the needs of this program. Explosives have been provided for the Gasbuggy and Rulison events, but these have been spillover from the weapons program. They have left much more tritium than would be left by a specially designed device.

In order for our current design calculations to be most productive, we have made decisions as to the explosive characteristics to emphasize at this time. It appears to us that tritium is of prime importance. Reduced diameter is important, but is probably not worth the price of greatly increased post-explosion tritium. Also, multiple explosions in one hole can reduce the importance of diameter. Thus we have reached a compromise design goal of very low tritium in an explosive of reasonable diameter.

It now appears that we can provide within a year an explosive of less than 12" diameter at a yield of 50 kt and with a very low level of post-explosion tritium. This device would be able to withstand the environment of deep gas stimulation. With additional time for device development and at additional dollar cost per device, an explosive with essentially the same post-explosion tritium and environmental hardness but with a smaller diameter could be developed if necessary. Again the question of diameter should be decided on the basis of over-all system studies. I must emphasize that these statements of what we can do are based on our technical capability and not on our budgetary condition.

Ternery fission in which a triton will be released occurs with a frequency of 1 in $10^4$ and thus sets a lower limit on post-explosion tritium of about 0.1 mg/kt. It is probably impossible to keep all neutrons from the soil since delayed neutrons from the fission fragments are emitted with half-lives of up to 56 seconds. If about one-half of these delayed neutrons were captured in soil, they could contribute an additional 0.1 mg/kt of tritium. Thus a reasonable lower limit on tritium is $\sim$0.2 mg/kt or 10 mg from a 50-kt fission explosion. This limit could be approached only with a fission explosive with essentially no prompt neutrons reaching the soil or producing tritium in shielding materials.

C. Scientific

Previously reported experiments conducted by both the Lawrence Radiation Laboratory and the Los Alamos Scientific Laboratory have achieved an effective neutron fluence of approximately 13 gm-moles of neutrons per square centimeter.. An experiment conducted by LRL this past summer, the Hutch event, appears to have achieved a fluence about a factor of three higher. Since this entire scientific area will be discussed in detail in another session, I'll forego additional discussion at this time.

Summary

In summary, nuclear explosives have been and can be designed especially for Plowshare applications.

A. Up to this time, excavation has received the major emphasis, and the excavation explosive will be in an excellent position for actual utilization if our presently scheduled experiments for this year are successfully carried out.

B. An explosive especially designed for hydrocarbon stimulation has not been tested, but the current paper studies show that some designs are very promising. A tested design leaving a very small amount of post-explosion tritium could be available within a year of commencing hardware effort.

C. A device to provide a very high neutron flux has been successfully tested, and the continuation of device design effort in this area depends on the scientific value of the information obtainable from such experiments.

Explosive design and development for Plowshare applications has always been an interesting problem. With technical requirements being more and more determined by a striving for the infinitesimal, the future for the explosives designer shows promise of being even more challenging.

A continuing program of device development is needed to assure the optimum explosive for each application at each point in time.